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DEVELOPMENT OF STANDARD AND CORRELATED DIMENSIONS OF MATERIAL-COMPONENTS IN SCHOOL CONSTRUCTION.

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THE OBJECTIVE WAS TO DEVELOP A CORRELATED MODULAR SYSTEM OF SCHOOL DESIGN WHICH WOULD PERMIT A VARIETY OF COMPETITIVE MATERIALS AND EQUIPMENT COMPONENTS TO BE MASS PRODUCED FOR SCHOOLS AND USED INTERCHANGEADLY AND FLEXIBLY. THE DEVELOPED SYSTEM PROPOSES FUNDAMENTAL AND SIGNIFICANT INNOVATIONS WHICH HAVE NOT BEEN ADVANCED BY EARLIER PROGRAMS. THIS SYSTEM IS NOT PREDICATED ON THE BASIS THAT A SINGLE SELECTED UNIT OF MEASURE--THE BASIC MODULE--MUST BE AGREED TO IN ADVANCE BY ALL PARTIES OF THE BUILDING PROFESSIONS AND INDUSTRY, THAT ALL PRODUCTION PROCESSES MUST BE GEARED TO IT, AND THAT MATERIALS MUST BE SIZED IN ACCORDANCE WITH IT. THE NEW SYSTEM RECOGNIZES THE NEED FOR AND PROPOSES THE USE OF MORE THAN ONE UNIT DEPENDING UPON (A) THE SPECIFIC PART OF THE PROCESS, (B) THE ORDER OF SIZE OR MAGNITUDE, AND (C) THE PARAMETERS OF THE PROCEDURAL STEPS UNDER CONSIDERATION. IT ALSO PROPOSES THE USE OF THE TECHNIQUE OF MODULATION TO ESTABLISH THE LINKAGE SYSTEM WHICH RELATES THE NETWORK OF GRIDS REQUIRED TO PORTRAY THE VARIETY OF DIMENSIONAL CHARACTERISTICS. IT FURTHER PROPOSES THE USE OF BOTH RIGID AND NONRIGID GRID COMPOSITION DEPENDING UPON SPECIFIC PROBLEM CRITERIA. IT WAS RECOMMENDED THAT ALL SEGMENTS OF THE SCHOOL BUILDING INDUSTRY BE ENCOURAGED TO STUDY, EXAMINE, EVALUATE, AND APPLY THE DEVELOPED SYSTEM FOR PURPOSES OF CRITICAL REVIEW. SPECIAL EMPHASIS SHOULD BE PLACED ON AN INDUSTRYWIDE EDUCATIONAL PROGRAM DESIGNED TO INFORM EDUCATORS, ADMINISTRATORS, ARCHITECTS, ENGINEERS, MANUFACTURERS, FABRICATORS AND CONSTRUCTION CONTRACTORS, AND THEIR RESPONSIBLE PERSONNEL ABOUT THE SYSTEM AND HOW IT WORKS. (JL)

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TEXAS EDUCATION AGENCY
AUSTIN, TEXAS
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Foreword

This research study report is concerned with the development of a dimensional coordinating system for school building design and construction.

The research reported in this publication was performed pursuant to the terms of a cooperative research agreement between the United States Office of Education, Department of Health, Education and Welfare, and the Texas Education Agency. The actual research was conducted by the Building Research Division of the Southwest Research Institute, San Antonio, Texas, under the direction of the Texas Education Agency through a subcontract approved by the United States Office of Education.

The objective of the study as outlined in the cooperative research contract was:

> To achieve the development of a correlated modular system of school design agreeable to both architects and building component manufacturers which will permit a variety of competitive materials and equipment components to be mass produced for schools, and used interchangeably and flexibly.

The general hypotheses were:

> It is possible to develop a practical system of modular design and construction.
>
> The system should provide more classroom space in a shorter period of construction time for the funds expended.

The report first describes several separate related studies which were performed to gather pertinent information for developing a system for dimensionally coordinating modular design for construction. It then details the system, including its pertinent segments, tools and aids and uses by the various segments of the building industry, and finally relates the system to two previously constructed school buildings.

The project was directed by Leon R. Graham and coordinated by Charles T. Roberts of the Texas Education Agency. Stewart D. Barradale, Southwest Research Institute served as research director and was assisted by Norman I. Turner and Paul Garcia, Institute staff members. Valuable assistance was rendered during the program by L. D. Haskew, Ernest J. Kump and J. Stanley Sharp, consultants to the research staff. Acknowledgement is made to Edward H. Guice, Consulting Architect, Texas Education Agency, and to the Project Advisory Commission composed of representative architects, engineers, school administrators, school board members, contractors and fabricators for their contributions. Appreciation is expressed also to the many individuals, firms and organizations which were contacted during the study, a list of which appears in the Appendix.

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ABSTRACT

The purpose of this research project is to advance the frontier of knowledge in the field of school building design and construction by developing a method for skilled technicians to create dimensionally coordinated school buildings which will meet the needs of educational programs.

School building construction involves a large number of people possessing a variety of particular abilities and skills. All are concerned to some degree with various tasks aimed at creating quality space and environment for educational programs of increasing complexity.

The problem statement can be reduced to a single question: By what method, system or technique can the necessary segments, tools and aids be provided to allow the responsible skilled groups to create dimensionally coordinated school buildings which will meet the needs of the educational processes? The answer to this question is that a broad, flexible modular system for design and construction, which relates building spaces, elements, components and material systems with the processes of planning, design, fabrication and construction, is the only presently proposed feasible technique.

Research Procedure

The conduct of this program includes several methods and techniques customarily employed in research endeavors involving both broad concepts and intimate detail. These are:

1. A studied review of pertinent literature related to the nature of the school and to the modular concept, i. e. historical development, previous work and achievements;

2. Contacts and conferences with persons in fields related to school building design, construction and modular research;

3. Inspection, study and analysis of the dimensional characteristics of recently built schools;

4. Review and analysis of the dimensional aspects of building material parts, components, and systems;

5. Review of school building costs;

6. Development studies concerning fundamental areas specifically applicable to the development of a reference system for school building design and construction; and

7. Application studies involved in the methods, processes and techniques of design and construction.

The initial major task was the collection of background information and data and the investigations of pertinent subsubjects regarding the status of the various arts and their content and meaningfulness to this project. The first subsubject concerned the nature and influence of the school as related to American education and school plant policies and procedures. The modular concept including philosophy, achievements and status was the second area of interest. These reviews provided valuable background for the staff and also offered the opportunity for considering untried or unproved approaches. These two subsubjects were studied by reviewing pertinent available published documents of all kinds and by meeting with many individuals who had worked in one or more of the areas.

The next subsubject involved the gathering and study of the architectural and structural contract drawings for 127 recently built schools. Dimensional characteristics of the various activity spaces, building materials and material systems and building elements were of particular interest, since the purpose of this program was to develop a dimensional reference system.

To insure a proper and sufficient foundation, further effort was spent in studying and analyzing the dimensional aspects of building material parts, components, and systems. This procedure augmented the prior mentioned studies and provided the material information needed to establish the broad base of the dimensional facet insofar as existing information and conditioning influences were concerned.

Two additional subsubjects related to the nondevelopment portion of the program were studied. The first concerned school building costs in relation to the system to be developed. The second involved the study of volume (space) as required by various activities carried on in a typical elementary classroom. Both were conducted to investigate further the significance of the system under development and to explore avenues of approach.

The second major task required a variety of studies which were fundamental and practical. These studies were directed toward the development of the reference system and associated techniques as related to existing procedures and practices. Significant among these were number relations, including the study of number patterns and number combinations; modulation, involving methods and techniques; proportion and its import regarding design; planning processes and the linkage with modulation; and building elements as related to buildings; the modular complex and the system for design and construction. The results of these studies as conditioned by the previous background review and investigations established the methodology, set the procedures, and formulated the tentative system.

The third major task involved the application of the tentative system to numerous isolated examples for purposes of evaluation. This application is a part of the molding, adjusting and modifying process required to determine or identify the essential component parts or portions of the system. Also involved in this task was

the application of the system to two schools which represented differing design parameters.

Significance to the Responsible Groups

The educator-administrator, architect-designer-engineer, manufacturer-producer-fabricator, and construction contractor-trades group, each must think, design and work in terms that will produce orderliness. Each must voluntarily invoke those disciplines which will allow this achievement. Without order, thought processes, design solutions and resultant works will become confused, incoherent and inconsistent. Thus, the subject of this research project involves the study and development of a method to guide, assist and foster dimensional order throughout the total design and building process.

The educator-administrator should think in terms of dimensional order when developing those parts of the educational program which will establish criteria for a particular building design and also when reviewing for acceptance the proposed preliminary designs. The lack of awareness or an oversight will affect adversely the functional operation of the school plant throughout its useful life.

The architect-designer-engineer must emphasize dimensional order during the thinking, planning and designing processes which are involved in creating a building. Obviously this is not a new thesis. It is well, however, to restate that both the analysis and synthesis of dimensional aspects as related to design and construction are of paramount import. These dimensional aspects can be achieved at the site by cutting and fitting. They can be accomplished also in the shop if (1) sufficient emphasis is devoted to them during the planning, designing and detailing states and if (2) the over-all applicable method as developed is utilized.

The manufacturer-producer-fabricator also must think, design and produce in terms of dimensional order. This is particularly true if the manufacture of building products is predicated on the philosophy of producing stock parts or components which may be incorporated into the design of a specific building. Obviously, the result would be the elimination of refabrication at either the shop or site. Recognition of both the need for dimensional order within a material and the significance of dimensional compatibility with adjacent systems cannot be overstressed.

The construction contractor-trades group is a major segment of the building industry. If dimensional order is to result, this group must recognize its value and contribute to the accomplishment. Advance planning, scheduling and quality workmanship by all craftsmen as well as recognition of the tasks and achievements of successive constructions are necessary attributes which must be considered in terms of their related dimensional aspects.

Since all these groups have responsible parts and since the developed method or system is a tool or an implement necessary to the efficient prosecution of all skills and trades, it is, therefore, particularly appropriate and wise to study and understand the depths of the proposed method.

Summary of Development, Findings and Conslusions

Most prior efforts involved in the study of the modular concept have been concerned with the material or product size, the industrial processing or production of construction units and the concept of piece-by-piece assembly. Thus, these efforts would, if successful, enhance or improve the position of the material producer-fabricator by improving dimensionally the end products for buildings. This is an admirable approach but it must be recognized that there are other significant considerations involved in the creation of enclosed space.

The concept in this research is predicated on the idea that buildings comprise determined finite spaces bounded by material planes of different lengths, widths, and thicknesses and that these spaces, elements and materials can be linked dimensionally and made commensurable if all are founded on a dimensional reference system sympathetic and compatible with the parameters and processes of programing, design, production and assembly. Thus, it is of paramount importance that an over-all dimensional reference system, method or technique be developed for school building design and construction in which there is flexibility as well as the attributes of dimensional control and discipline to be exercised, if so desired, by those employing the system during the various processes of building.

The developed system proposes fundamental and significant innovations which have not been advanced by earlier programs. This system is not predicated on the basis that a single selected unit of measure--the basic module--must be agreed to in advance by all parties of the building professions and industry, and that all production processes must be geared to and that materials must be sized in accordance with the selected unit. It recognizes the need for and proposes the use of more than one unit depending upon (a) the specific part of the process, (b) the order of size or magnitude, and (c) the parameters of the procedural step under consideration. It also proposes the use of the technique of modulation to establish the linkage system which relates the network of grids required to portray the variety of dimensional characteristics. It further proposes the use of both rigid and nonrigid grid composition depending upon specific problem criteria. The system possesses flexibility the degree of which can be controlled, as required, to meet the specific needs as determined by and at the discretion of the designer, fabricator or contractor.

The system is best described as a methodical order of coordinating dimensions for building spaces, building elements and materials and to help coordinate building construction details. It consists of primary segments and supporting tools and aids. The segments are the establishment of the frame of reference by identification of principal planes of reference, modulation, correlation, and coordination. These are stated in their relative order of use sequence within the system's total application. The supporting tools and aids are modulation methods, number pattern, number combination tables, grid patterns, and symbolic representations. The supporting tools and aids may be applied within any of the segments and have no particular relation to sequence in application of the developed system.

This project does not demonstrate conclusively that full use of modular coordination will reduce the cost of a particular school building by a definite percentage. It does indicate that economies in cost should result through the utilization of more prefabricated dimensional components of standard sizes and through a reduction in on-site construction time.

1. INTRODUCTION

Worthwhile architecture is a direct product of the social character and technology of the times. Also, beauty, imagination, aesthetics, and utility or function are best served by the aids advanced by technology.

A fundamental element of today's technology is the concept of modular coordination. Extension of this technique in some form is inevitable. Failure to pursue and exploit the potentials would be to deny architecutre a great technique of its day and of the foreseeable future. In an ever-increasing mechanized environment failure to extend the usefulness of a coordinated system of dimensional reference would be to stultify the usefulness of industrial and technological advancements and limit the scope of design techniques in present-day architecture.

Tomorrow the number and range of material components will be extended and innovated by the producer. It is mandatory that these building materials be studied carefully in collaboration with the architect or designer and the producer not only to insure that they are acceptable aesthetically, functionally, and for proper utilization, but also that their size range and variety correlates with an acceptable system of dimensional reference for design and construction. Thus, the application of this facet of our technology will exclude any tendency either to restrict design, produce sterility, or allow the production of a series of materials not fully coordinated.

As a part of this technology, new theses have been studied and proposed. Generically, five different modular concepts or approaches were identified during the conduct of this endeavor. Objectively, these are categorized as follows:

1. The Bemis concept called "the cubical modular method," applicable to industrialized low cost housing in the early 1930's.
2. The approach of the American Standards Association to Modular Building Standards Association concerning material sizing based on the 4 inch unit and schematic drafting (referred to today as modular measure).
3. The E. J. Kump concept named "the basic space module" which is a large "block" of space basic to the criteria of a specific design program and which is repeated in the design.
4. The E. D. Ehrenkrantz approach involving the nature and advantages of modular coordination, range of product sizes and design flexibility based on the number relations of both the 3 inch and 4 inch basic units.
5. The leCorbusier works concerning the proportionate scale as a design tool and the "blue and red series" for product sizing.

The second listed approach has been by and large the greatest and most publicized effort. It has met with specific resistance, however, from certain individuals and groups well versed in the field. The four other contributions listed are viewed as concepts, approaches or techniques concerning design, number relations, ranges of product sizes, etc. but not as the full range of segments, tools and aids of a complete system applicable to all processes.

A. Problem

The problem is to develop a workable system or method of modular coordination for school building design and construction that will not only provide the opportunity for a reduction in the cost of component parts and in the cost and time required for the entire building process but will permit complete design flexibility.

The problem is particularly significant since there is:

- a definite lack of basic research in the area of school building design and construction,
- a deficiency in research studies involving dimensional relationships as they concern the various segments of the school building industry,
- a need for better understanding of the import of dimensional interdependence in regard to design, fabrication and construction assembly, and
- a desire on the part of all concerned to improve the efficiency and techniques of the educational building effort.

This research is of prime importance because of the tremendous need for additional school plant facilities. Today there is a pressing demand which requires skill, ingenuity and arduous effort to improve our educational stature. This demand has not only presented the challenge but also, of necessity, has provided the opportunity to achieve efficiencies through research endeavors.

B. Objective

The objective of this research program is to advance the boundaries of knowledge and to achieve the development of a comprehensive dimensional reference system for school building design and construction which is:

- acceptable and agreeable to the educators, designers, manufacturers and contractors;
- consistent with the duties, procedures and responsibilities associated with each of the aforementioned groups; and
- sympathetic with the requirements of the individual and collective efforts of the above groups.

Once accomplished and utilized within the total industry, the system will permit the inclusion of the great variety of mass-produced competitive materials and equipment to be used interchangeably as required by each school program and design.

It is here emphasized that this research study does not seek a dimensional reference system of or for prefabricated or standardized school buildings, proprietary building element systems, or special and specific building materials and material systems. Such a method can be of little value unless and until it accords the flexibility of design and multiplicity of selection that is now available to educators and

designers. A dimensional system founded on broad concepts and containing inherent flexibility as required by normal practices will possess all of the qualities needed for the more specialized practices.

The general hypothesis is (a) that it is possible to develop a practical system or method of modular coordination for school building design and construction and (b) that the employment of the techniques will provide more teaching-learning space in a shorter period of construction time for the funds expended.

C. Scope

This research program is purposely limited to specific parameters at the outset. It comprises various tasks and studies normally associated with research design and development exclusive of experimental and laboratory work. This work involves a dimensional reference concept as related to:

- the educational complex--its philosophy and programing, practice and procedures;
- the modular complex--its history, development and present status;
- practices and procedures in architecture and engineering;
- manufacturing of building units; and
- building construction, erection and assembly.

Thus, the scope of the program transcends a typical development project which might be concerned with a tangible end item and physical mockups or experimental models. It encompasses all those persons or groups interested and participating in school building design and construction. The scope is established to develop the methodology and techniques necessary to allow for the creation and construction of orderly arrangement of spaces, building elements and building units and to produce the physical sizes and shapes of material units for these constructions according to a basic dimensional system. The scope of the effort involves avenues of search, therefore, that will lead to an affirmative, workable conclusion.

D. Approach

Of paramount importance at the outset is the understanding that the procedure for design and construction of a school building is a complex procedure which requires not only analysis, evaluation and synthesis but also a great variety of artisan and scientific skills in the areas of educational and architectural programing, design, fabrication, and construction.

Basic research programs regarding projects of this size and scope require the employment of many methods and techniques which are the detailed tactics utilized to accomplish the various tasks. These techniques include the search of pertinent literature, verbal and written communication with others, inspections, reviews, development studies, analyses, evaluations and trials. All are necessary in one

form or another for an understanding of the problem and its ramifications and for developing a realistic solution.

There are three principal tasks or phases. The first deals with several areas which involve the gathering, study, and analysis of information to provide background, understanding and the opportunity for significant development. The second comprises various basic research and development studies which when completed, provide the endeavor with the tentative results. The third and final effort involves the determination of the essential component parts of the system and the evaluation of it by applying it to two specific examples.

The first two major tasks contained several substudies which are presented in Sections II and III. Section IV describes the system developed and Section V contains the two example applications resulting from the efforts of a third task. Significant findings and conclusions are presented in Section VI.

2. ANALYSES OF SCHOOL DESIGN

A. Introduction

Basic research projects require investigation and analyses which deal with the earlier works of others, the status of present information and know-how, and the study of fringe subjects. Such efforts although pertinent are not a part of basic research and development per se. Their significance is that they provide background and indoctrination and thus the opportunity for knowledgeable development. They comprise data collection and comprehension and result in a formulation of parameters to assist the more basic effort.

This section summarizes five such studies and analyses which were performed. Each is discussed to indicate scope, content and meaningfulness to the overall research program.

The first is entitled "Background Study." This involves three separate activities, i.e. (1) a review of the school complex, (2) the historical background and basic contributions to modular coordination and modular complex, and (3) personal contact with individuals concerned with activities 1 and 2. The purpose was to familiarize the research staff with the extent of work by others, to understand the significance of these efforts as related to the general and specific problems to be encountered, and to attain an awareness of the ramifications involved.

The second, "School Sample Study," comprises the dimensional analysis of the activity spaces and material elements and systems of recently built schools. This effort not only indicates certain broad and detailed dimensional characteristics but also provides some degree of insight regarding problems and solutions which reflect the needs of particular educational plants evidenced by the designs.

The next study, entitled "Material Parts Survey," reviews in detail the dimensional characteristics of existing building material parts, components and systems. The purpose is to understand not only the dimensional aspects of the individual material parts and components, but also the import of their dimensional relationship when incorporated into material systems. Increments of assembly with variations were observed so that due consideration could be given to multiple assembly of pieces.

The fourth study concerns "School Building Cost," which is considered by some to be of primary importance. The purpose is that if meaningful and comparative data can be assembled, the advantage of utilizing a system for dimensional control in school building design and construction can be substantiated by economic facts. Available information is collected and analyzed.

The fifth involves the study of volumes (space) as required to meet the needs of any prescribed program. The purpose is to develop a method so that the several functional requirements can readily disclose the three dimensional aspects of a space or volume. The example presented depicts the volumetric build-up of an academic

classroom based upon the type and disposition of subactivities, size of occupants, population, mechanical environment, and particular equipment.

B. Background Study

Education Characteristics

The Background Study was the initial task undertaken by the research staff. Since this research effort is essentially the development of a system of Modular Coordination for School Design and Construction, the staff first studied the nature of schools. What is involved in the concept of the school building category, and what are the influences which justify the particular aspects peculiar to this category? What determines the particular educational requirements and material nature of the physical plant?

The exact school program in a particular community and the physical facilities provided to assist in the implementation of the program are dependent to a large extent on the nature and desires of the community itself. All public school programs are conditioned by the over-all objectives of our democratic society and in each state conform to general state standards and program requirements. Local school systems, however, normally have a great deal of latitude in developing their own educational philosophies and in planning the detailed programs they believe will best serve these philosophies.

The school in the rural community usually differs in program and in building needs from its urban counterpart. The rural or consolidated school may stress agriculture, homemaking, and commercial subjects in addition to the regular academic program. The urban school system with its larger enrollment may include two or more foreign languages, advanced science and mathematics courses, and fine arts, as well as a wide range of vocational courses.

Again, the smaller school system may have the entire school population housed in one building or at the most in two, one for the elementary program and another for the secondary school. The larger system usually includes elementary, junior high school and high school buildings and often separate structures for such special programs as those for the mentally retarded and orthopedically handicapped.

Finally, the rural or small town school system may need to provide facilities for community functions which are not required in the more populous areas where auditoriums and coliseums are the responsibility of the municipalities. Thus, the size and nature of the school community exert a pronounced influence on the school program and its necessary physical facilities.

The financial resources of a school district also have a direct influence on the physical facilities which are made available. It is only natural that those school systems with excellent financial bases should provide more modern and complete

school plants than those found in districts with limited financial resources. The desire of the citizens, however, plays an important role. School patrons are often willing to assume additional tax obligations in order that adequate school plants may be constructed. More and more smaller school districts are accomplishing this objective by joining other school systems so that there may be both an adequate number of students for a comprehensive school program and the financial resources to sustain its operation.

School building design is influenced also by the site selected. The location, orientation, approach, site planning, and landscaping all contribute to the physical exterior environment. The relationship of the classrooms and supporting spaces are studied and resolved with regard to the environmental criteria. The design detail which includes proportionate relationships of space, elements, vistas, light and shade, color and texture, and the grouping of finish materials will condition the sensory or emotional environment created by the school building.

Finally, any school building must conform to specific local conditions such as fire, building, and safety codes as well as regulatory state statutes. These vary from municipality to municipality, from urban to rural areas, and from state to state.

The obvious conclusions derived from this study are:

(1) There are many valid factors which influence both the education programming and the architectural planning or design of the school plant.

(2) These factors impose different and varying requirements which influence the size, the design plan, the functions and type of each individual school plant.

(3) The form and solution for the school facility are dependent not only on the educational program, but also on the communal functions, on the particular site and local conditions, and on the codes or regulatory statutes.

Thus, any definitive or proprietary standardization of school plants is unrealistic and is fundamentally contrary to school planning in the United States as conceived today and in the foreseeable future.

Modular Coordination

The second portion of the background study was the search to determine what has been accomplished to date in the area of modular concepts. It comprised the exploration of work already undertaken which was related to any aspect of the subject of modulation. There were evidences that substantial contributions have been made along certain lines of this concept. Beginning in the United States and continuing here as well as in Great Britain and in other nations of Europe, the general principle has been given considerable study and has been gaining interest.

Development in the United States

Modular or grid concepts related to the design and manufacturing of building products and material systems can be traced back to the early twenties and thirties when Fred Heath wrote and talked about them and Albert Farwell Bemis, an industrialist, began his pioneering research on this subject. It was not until the authoring of The Evolving House, Volume III, Rational Design by Mr. Bemis, however, that interest began to spread. The main object of his studies was to use dimensional coordination as a means of lower cost and improving the quality of low income family housing. He considered his concept a technique and called it "the cubical modular method."

Bemis' axiom was that if all building products were multiples of a base module, they would be readily commensurable. He examined several basic dimensions in detail and suggested two as workable with United States products, i.e. the 3-inch and 4-inch basic units. After Mr. Bemis' death in 1936, his heirs proposed to the American Standards Association that a project be initiated to study the coordination of the sizes of building products. The Modular Service Association was formed as a sectional committee of the American Standards Association to carry out this work. By 1938 the program was initiated under the title of ASA Project A63 for the Coordination of Dimensions of Building Materials and Equipment. The American Institute of Architects and the Producers' Council were joint sponsors. The working group represented the building industry and consisted of architects, engineers, contractors, manufacturers, consumer groups and government agencies. One result of this work was the formal adoption by the American Standards Association in 1945 of the 4-inch module as a standard basic unit suitable for dimensional coordination. Funds allotted this project had been exhausted by 1946. The Federal government, through the Office of Technical Service, appropriated additional funds to support completion of the final year's work. The result of this effort is the book referred to as the A-62 Guide. The beginning made by Bemis and the publishing of the A-62 Guide were the first major collective efforts to advance modular concepts.

The Housing Act of 1948 authorized the Housing and Home Finance Agency to standardize dimensions and methods for the assembly of home building materials and equipment. Thus, interest was evidenced by the Federal Government. As part of its activity, the Housing and Home Finance Agency played an important role in the distribution of information on the subject. The first publication, Report on a Survey of Factors Hindering More General Acceptance of the Modular Principle in Design and Construction created so much interest that subsequent documents were issued to indoctrinate individuals associated with the building industry in the broad aspects of this modular concept.

Under auspices of the American Institute of Architects emphasis has been on building, planning, detailing and drawing. Publications have been released concerning the establishing of more efficient procedures in the practitioners' offices. The Institute also compiled and published a listing of products and producers of products that were being manufactured in multiples of the 4-inch module.

Recently interest in this modular concept has regained momentum. The Modular Building Standards Association was formed under the joint sponsorship of the American Institute of Architects, the Associated General Contractors of America, the National Association of Home Builders, and the Producers' Council, Inc. One of the goals of this new association is to standardize building materials and product sizing in conformance with the 4-inch module. Another is to counsel the manufacturers in their selection of ranges of material sizes.

The contributions made by individuals and independent organizations cannot be overlooked. Certain manufacturers have initiated programs aimed at developing a well-established relation of their products with the principles of modular coordination. Among these are the clay and masonry producers and the window and window-wall manufacturers, who through continuing work have established efficient techniques in the design and assembly of their products.

The accomplishments of the individual architect and designer in the use of modular construction should also receive mention. Some have worked continuously with certain phases of the modular concept. It has been through their individual efforts and continued practice that more attention has been focused on the subject of modular coordination. The principles and advantages of this approach are now being noticed by many persons concerned in the building industry.

In Great Britain

The basic need for research in the area of dimensional coordination has arisen from the ever-increasing number of elements produced by the manufacturers. The British felt that the attempts to find a systematic relation between items and to insure their assembly on the site through standardization would be of great value.

Britain's rebuilding program as well as postwar economic conditions afforded a background for the very rapid development of dimensional standardization of all types of building products as promulgated by the British Standards Institute. Federal and local agencies had a tendency to make use of the British Standards as a requirement in their work. Dimensional standards were established by each industry, however, and bear little or no relation to one another. Discrepancies in sizes were overcome by "cutting and fitting" or using nondimensional materials, such as plaster, or by using special custom materials.

The main factor that slowed progress toward total coordination of building products was the lack of direct and noticeable financial advantage to industry. The incentive was not expected to originate in industry but from those individuals who were responsible for large scale building programs. Consequently, when the Ministry of Education was faced with an enormous building program, the use of a dimensional module for design was recommended. This medium was to provide for the systematic production of the necessary building components. The supporting facts were presented in the Report of Technical Working Party on School Construction.

The Ministry of Education school building program was initiated in 1947. Its development became a major building effort. Two committees appointed by the Ministry reported on the best means for securing rapid and economical construction of schools. They concluded that the only way to solve the problem was to make use of some common dimension in design. The Wood Report proposed a standard bay size of 8 feet, 3 inches which resulted in many schools being designed and built with this dimension as a basis. In some cases it was used only in one plan direction and in others in both directions. A considerable number of sized components, including structural frame members, windows and slabs are now in production as a result.

The Wood Report was succeeded by the Report on the Technical Working Party on School Construction, reaffirming the general conclusions of the Wood Report, i. e., the need for a modular plan in school building. It noted difficulties, however, which had arisen from the selection of the 8 feet, 3 inches dimension. Profiting by previous experiences the Working Party Report recommended a structural bay spacing of 10 feet, thus allowing it to form the planning grid. Many schools were planned on this one structural module basis. Insufficient time has elapsed since this decision was made, however, to provide verification data.

Among the many schools designed and built on the basis of 8 feet 3 inches, those of the Hertford County Council, designed by the County Architect, are of special interest. These school plans are composed of standard elements to an unusually high degree. Many of the difficult problems such as the treatment of angles and wall intersections, were solved by the use of systems of construction, but the effect of standard dimensions on aesthetic design was questionable.

In European Countries

During World War II, Germany adopted the planning dimension of 1.25 meters (approximately 4 feet) as a module which was considered satisfactory for their vast building program. In order to accomplish construction necessitated by the enlarged postwar rebuilding program, the Germans neglected development of new forms of systems of construction and devoted their efforts toward improving the output of conventional work. They introduced a number pattern system, however, based upon a range of preferred sizes which integrated dimensional coordination with German standards. A requirement was established which stated that planning and construction must be based on these standards whenever government subsidy was sought. Although application varies, some three-quarters of their 400,000 houses constructed in 1953 employed sizes based on masonry units. Therefore, the dimensional aspects of these designs were based on the dimensional characteristics of a specific group of material systems (the German standards).

In Schleswig-Holstein, a zone in Germany, this system of construction was used in the building program. Here a society, called The Working Team for Up-To-Date Building, was formed in addition to the central government organization. Its function was to encourage cooperation among various trades concerned with building

construction. A limited number of modular standards were chosen based on a prescribed set of room sizes, house depths and roof pitches, and were incorporated in the original design of a structure. The production of standard products and assemblies was organized to correspond with these designs.

In Sweden, the Swedish Standards Association organized a study and issued material standards for the building industry. The first of these standards concerned doors and windows. The Association concluded, soon after production of a limited number of standard components, that it was necessary to seek a common dimensional basis. Lacking funds for necessary research in this field, it appealed to the Federation of Swedish Industries for support. Two Swedish architects (Bergvall and Dahlberg) were commissioned to study and report on the problem. Their proposals followed closely those of the building industry in the United States. Sweden, like other Scandinavian countires, for centuries has been famous for its clay products. Existing brick dimensions, however, as an example, were not compatible with the proposed system; therefore, it was necessary to recommend new standard sizes.

Work by other Western European countries to establish standardized systems of dimensioning follows a similar history to that of Sweden. Italy, France, Belgium and Norway established their own standards based on the decimeter (10 cm).

In France, however, another avenue of study was also pursued. LeCorbusier became interested in the design aspects of the modular concept. He was interested in determining if tools or design aids could be developed which would allow the designer to dimension space, building elements, and material components according to an aesthetically pleasing proportionate mean. Furthermore, he set about relating this mean to the human form. Since buildings are primarily designed for people, the scale employed in design should be based on body measurements. "Le Modulor," a scale he developed from his studies, embodies two basic concepts:

(1) The aesthetically pleasing proportionate mean which he selected was the Golden Mean or Golden Section (1.618). This is the proportionate mean used through the ages by architects and craftsmen in some of the most noteworthy and beautiful buildings of the past.

(2) The dimensions he resolved from human body measurements were a basic series consisting of 43 centimeters and 113 centimeters, which are in the same progression as the Fibonacci series--3, 5, 8, 13, 21, 24--.

Le Corbusier then expanded the Fibonacci series into two number series patterns called the Red Series and the Blue Series. These he used as a correlation medium to relate ranges of dimensions for design and for product or material sizing.

In 1954 the European Productivity Agency embarked on a project to study the subject of modular coordination. This was an effort to search for a possible solution to reduce the building time and costs for a tremendous housing need. The need arose from obsolescence in present housing, from an increasing population, and from a shortage of units due to war losses. The social and economic problems of

the times moved the European Productive Agency to undertake this project. Eleven European nations are taking part in the study with the United States and Canada as observers.

The first phase of the project reviewed the experiences and present position of each of the participating countries with respect to modular concepts and practice. The second phase involved the construction and evaluation of test buildings by the various countries using various particular modular techniques. As a result of this combined effort, it is hoped the European Productivity Agency will be able to draw conclusions regarding the general practical application of modular concepts to this building category. The entire effort is a search to provide techniques through modular concepts that will utilize more economically and efficiently the countries' industrialized production and will lead to more realistic standardization of building components or materials.

In summarizing the accomplishments in the area of modular concepts, it can be said with emphasis that a considerable number of valuable contributions have been made and that efforts and attempts to accomplish coordination are widespread throughout the world. It is obvious, however, that the work accomplished to date falls into two categories or areas within the modular concept. One is the development of particular systems of construction for a certain range of designs, where a certain range of materials and material sizes are used within the closed construction systems. The other category is termed "The Modular Coordination System."

The first category of accomplishments is represented by (1) the British County Council System for School Construction sponsored by the Ministry of Education; (2) the German efforts in housing during World War II and in the reconstruction period following the war; and (3) the Swedish Bergvall and Dahlberg systems. This approach to modular coordination is not tenable for application in the United States for school design and construction. As has been pointed out above, any effort to standardize or develop proprietary schemes of school plant design and construction is contrary to school planning needs as conceived in the United States today.

In the second category of accomplishments, "The Modular Coordination System," the "System" means a discipline or technique which begins at the design phase of a building program. With the use of certain methods, tools or aids, dimensional coordination is achieved for the various portions of the building program from planning to final assembly on the site. This procedure will not limit the design to any particular construction system.

C. School Sample Study

At the beginning of this cooperative research program, it was considered desirable to conduct a sample survey of recently designed and constructed schools for three specific purposes:

(1) To provide background data to better understand the complexities of recently constructed schools.

(2) To serve as a source of dimensional data to assist in the development of the tentative modular system.

(3) To be used as a tool to assist in evaluating the modular system under development.

Early efforts to determine the size of the sample dealt with numerous variables, such as (1) requirements of departments or boards of education; (2) different kinds of educational programs; (3) subsidizing agency regulations; (4) regional and climatic considerations; (5) population and land development trends; (6) local site conditions; and (7) materials and construction labor. The survey sample included examples of recently constructed school buildings throughout the nation which would reflect many of the variables found in schools.

During the development phase, a group of selected examples of the total sample was reviewed with regard to dimensional aspects. These data such as academic classroom lengths, widths, and heights, and horizontal and vertical dimensions of material elements were recorded and studied. This effort was to discover in a limited way which dimensions, if any, were frequently employed; what the various sizes of building and material elements were; what dimensional subdivisions were used, etc. The frequency of recurrence of like dimensions was of particular interest since this recurrence could, along with other information, assist in guiding the development of the total modular system.

Sample Description

Criteria for selecting individual examples were established as a guide. Since this cooperative research project concerns a System of Modular Coordination for public schools, the first consideration was that it be national in scope, thereby eliminating any singular group of local or regional requirements. Next, the sample was to include both elementary and secondary grade levels. In addition, other school characteristics included were: urban and rural, single and double stories, unilateral and bilateral lighting, single and double loaded corridors, material system and plan shape variations. A broad cross-sectional basis was thereby provided for the collection of dimensional data which would not reflect any special or individual conditions. The designs were to represent, insofar as was possible, good solutions of school plant facilities.

The informational sources for the selection of the individual examples used in this sample study were:

(1) Current and morgue material in the files of Architectural Record, Progressive Architecture, Architectural Forum, and The School Executive.

(2) The list of schools selected for the Geneva School Building Exhibit, July, 1957.

(3) The lists of schools included in exhibits at the American Association of School Administrators' conventions for the years 1953, 1955, 1956 and 1957.

It was determined at the outset that the size of the sample should include 125 to 150 examples. In order to insure the approximate number needed about 216 school designs were selected. Architectural and structural contract drawings and cost data were requested from 161 architectural firms. One hundred eighteen firms replied and submitted 127 document sets.

In the tabulations below and on the following figure, certain details of the sample are presented.

		Percentage		
		Guide	First 100 Selected Schools	Final Sample
A. Location (Number of States Represented)		100	32	--
B. Grade Level - Elementary		60	57	60
Junior High			14	
Junior Senior High		40	6	40
Senior High			23	
C. Location - Urban - Suburban		70	72	71
Rural		30	28	29
D. Number of Stories - Single		80	79	--
Double		20	21	--
E. Natural Lighting - Unilateral	no specific percentage required		58	--
Bilateral			43	--
Top			30	
F. Corridors - Double Loaded			52	--
Single Loaded			52	--
G. Plan Variations			--	--
			--	--
H. Material Variations			--	--

TABLE I -- PERCENTAGE DISTRIBUTION OF SAMPLE VARIABLES

Activity Space Designation	Grade Level Elem.	Jr.H.S.	Jr.-Sr.H.S.	Sr.H.S.	Sec.	Total
Typical Classrooms						
Math, English, etc.	917	288	195	288	771	1688
Other Classrooms	118	26	36	75	137	255
Total Academic Cl. Rm.	1035	314	231	363	908	1943
Music - Band	4	10	10	15	35	39
Chorus	4	6	6	9	21	25
Library	25	14	14	19	47	72
Reading	6	-	-	2	2	8
Speech	2	-	1	2	3	5
Corridors - SL	18	13	1	12	26	44
DL	83	32	35	46	113	196
Passage	53	1	6	6	13	66
Kindergartens	143	-	-	-	-	143
Arts, Arts & Crafts, Mechanical Drawing	8	18	20	38	76	84
General Science	-	18	17	18	53	53
Biology	1	10	9	26	45	46
Chemistry	-	-	6	17	23	23
Physics	-	-	6	17	23	23
Business Admin.	-	-	17	31	48	48
Typing	-	-	-	4	4	4
Home Economics	2	29	22	43	94	96
Shops - Auto	-	1	1	3	5	5
Metal	-	7	7	12	26	26
Wood	1	13	13	17	43	44
Other	-	5	8	18	31	31
Study Halls	-	2	2	3	7	7
Auditorium	10	11	9	15	35	45
Gymnasium	20	12	13	18	43	63
Cafeteria	21	14	10	18	42	63
Multipurpose	54	8	6	9	23	77
Theaters	-	2	-	2	4	4

TABLE II - NUMBER OF ACTIVITY SPACES CONTAINED IN SAMPLE

Data Collection

Data take-off forms were organized so that dimensional information could be recorded in an orderly fashion. The guides selected to establish consistency were as follows:

Information - School

Plan Dimensions

- were rounded off to the nearest 4 inch increment to furnish nominal planning sizes.
- were taken to the centerline of walls and/or partitions of all activity areas.

Vertical dimensions

- were rounded off to the nearest 1 inch increment because of the small order of size consideration.
- (roof heights) were taken from finished floor to under side of roofing.
- (ceiling heights) were taken from finished floor to under side of finished ceiling.
- (ceiling heights, where framing was exposed) were taken from the finished floor to under side of ceiling finish or under side of finished roof deck whichever was applicable.

Information - Typical Classroom

All dimensions were rounded off to the nearest 1 inch increment except plan dimensions. These were recorded in accordance with guides as indicated above.

Dimensional data thus recorded was tabulated and charged for the following variety of activity spaces and areas:

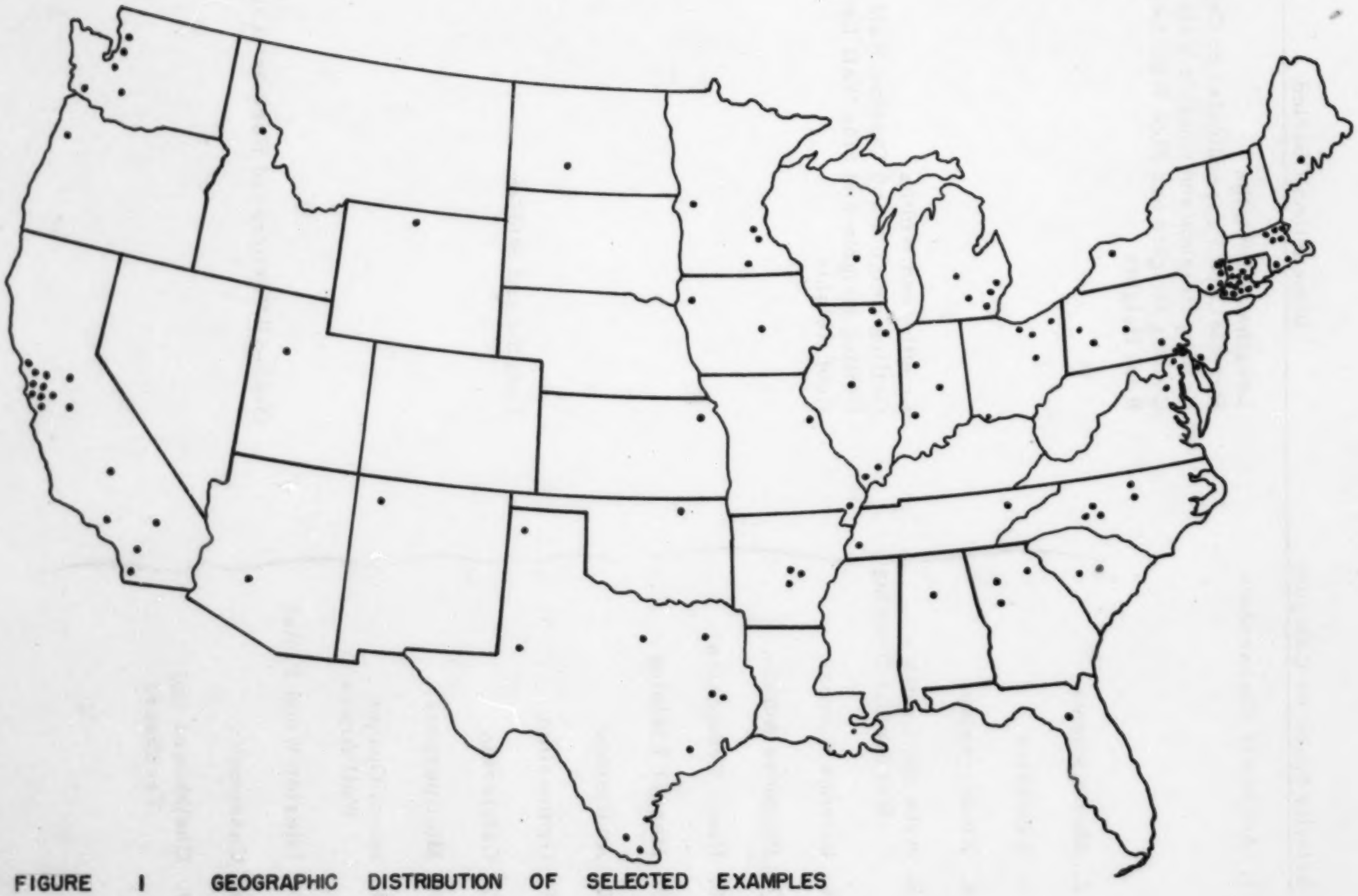


FIGURE I GEOGRAPHIC DISTRIBUTION OF SELECTED EXAMPLES

Activity Space or Category	Dimensions Charted
1. Academic Classrooms	Lengths and Widths Parallel and Perpendicular to Outside Walls Ceiling Heights and Outside Wall Lengths Ceiling Heights and Side Wall Lengths Roof Heights
2. Music Rooms 3. Libraries 4. Kindergartens 5. Arts and Crafts - Mechanical Drawing 6. Science Rooms 7. Business Admin. 8. Home Economics 9. Manual Training	Lengths and Widths Ceiling Heights and Outside Wall Lengths Ceiling Heights and Side Wall Lengths Roof Heights
10. Auditorium 11. Gymnasium 12. Cafeterias 13. Multipurpose	Lengths and Widths
14. Misc. Opaque Wall Areas 15. Interior Wood Finish 16. Casework 17. Chalkboard and Tackboard	Over-all Vertical and Horizontal Subdivisions

The prepared charts show: (1) the number of different sizes of each area, activity space, or category, per school, (2) the nominal size of that area, activity space, or category, (3) the total number of recurring dimensions in two directions, (4) percentages of recurrence, and (5) histograms of recurring dimensions. The tabulation and organization of other dimensional data reveal:

- the number of different sizes and types of classroom doors,
- the number of different areas or dimensional combinations of exposed masonry finish, and
- the number of different areas or dimensional combinations of transparent and translucent wall materials.

In the last two items directly above, the results varied over such a wide dimensional range and contained so few recurring dimensions that the usefulness of this data was questioned. For this reason they were not charted.

Certain nondimensional data were found in examining the collected examples, which were:

- the number of different roof and ceiling conditions for nine different activity type spaces,
- the number of different roof conditions for four congregational type spaces, and
- the materials and material types for the various constructions (use-applications.

Analysis of Data

The dimensional data contained in the various tabulations and charts have been analyzed to determine:

- if whole numbers in the foot scale have been utilized
- if there was a frequency of recurrence
- if there was evidence to substantiate the numerical coefficients 3, 4, and 5.

The planning dimensions for the various activity spaces were analyzed and the information indicates that:

- Sixty to seventy-nine per cent of all length dimensions are whole numbers.
- Sixty-five to eighty-five per cent of all width dimensions are whole numbers.
- There are 43 instances where the dimension was a multiple of 3 feet.

- There are 65 instances where the dimension is a multiple of 4 feet.
- There are 24 instances where the dimension is a multiple of 5 feet.
- There are 12 instances where the dimension is a multiple of 7 feet.

A summary of information gained from other dimensional investigations indicates the following:

(1) For Ceilings and Roofs

- More than eighty per cent of the frequently recurring height dimensions are multiples of the numerical coefficient 3, 4, or 5 when converted to inches.
- Many of the non-frequently recurring height dimensions are multiples of the numerical coefficients 3, 4 or 5 when converted to inches.

(2) For Miscellaneous Opaque Wall Areas

- Forty-seven per cent of the horizontal dimensions are in whole foot increments.
- Thirty-nine per cent of the vertical dimensions are in whole foot increments.
- Fifty per cent of the frequently recurring horizontal dimensions are multiples of the numerical coefficients 3, 4 or 5.
- One hundred per cent of the frequently recurring vertical dimensions are multiple of the numerical coefficients 3, 4 or 5 when converted to inches.
- Many of the non-frequently recurring height dimensions are multiples of the numerical coefficients 3, 4 or 5 when converted to inches.

(3) For Interior Wood Finishes

- Seventy-two per cent of the horizontal dimensions are in whole foot increments.
- Twenty-eight per cent of the vertical dimensions are in whole foot increments.
- Seventy-five per cent of the frequently recurring horizontal dimensions are multiples of the numerical coefficients 3, 4 or 5.

- One hundred per cent of the frequently recurring vertical dimensions are multiples of the numerical coefficients 3, 4 or 5 when converted to inches.

(4) For Casework

- Fifty per cent of the horizontal dimensions are in whole foot increments.
- Forty per cent of the vertical dimensions are in whole foot increments.
- One hundred per cent of the frequently recurring horizontal dimensions are multiples of the numerical coefficients 3, 4 or 5.
- Eighty-three per cent of the frequently recurring horizontal dimen- are multiples of the numerical coefficients 3, 4 or 5 when converted
- Many of the non-frequently recurring height dimensions are multiples of the numerical coefficients 3, 4 or 5 when converted to inches.

(5) For Chalkboards and Tackboards

- Sixty-six per cent of the horizontal dimensions are in whole foot increments.
- Fifty per cent of the vertical dimensions are in whole foot increments.
- One hundred per cent of the frequently recurring vertical dimensions are multiples of the numerical coefficients 3, 4 or 5 when converted to inches.
- Many of the non-frequently recurring height dimensions are multiples of the numerical coefficients 3, 4 or 5 when converted to inches.

(6) For Typical Classroom Doors

- Twenty-eight different sizes were required in six different material and type categories.
- Sixteen per cent of those specified were 3-0 x 6-8 wood.
- Fifty-seven per cent of those specified were 3-0 x 7-0 wood.

(7) For Exposed Masonry Finished Areas

- The distribution of dimensional data in both the horizontal (1 ft.-0 in. to 36 ft.-4 in.) and vertical (6 in. to 18 ft.-7 in.) directions is so dispersed that meaningful percentages are nonexistent.

(8) For Transparent and Translucent Areas

. The distribution of dimensional data in both the horizontal (1 ft.-0 in. to 11 ft.-6 in.) and vertical (9 in. to 10 ft.-1 in.) directions is so dispersed that meaningful percentages are nonexistent.

A summary of information gained from the nondimensional investigations indicates the following:

(1) For Roof and Ceiling Conditions

. The ceilings of most activity spaces follow the slope of the roof.

. Seventy-nine per cent of the nine different activity spaces listed have flat roofs and ceilings.

. Fourteen per cent of these spaces have single sloped roofs and ceilings.

. Three per cent of these spaces have double sloped roofs and ceilings.

. Sixty-nine per cent of the congregational activity spaces listed have flat roofs.

. Seven per cent of these spaces have single sloped roofs.

. Twenty-four per cent of these spaces have double sloped roofs.

(2) For Materials and Material Types

The buildings in the School Sample included a wide variety of materials in a variety of combinations. After tabulation, it was evident that further effort would produce no additional significant results.

Conclusion

The Sample Survey indicates that:

(1) A large percentage of the length and width dimensions are whole numbers in the foot scale.

(2) The frequently recurring dimensions are multiples of the numerical coefficients 3, 4 or 5.

(3) In most instances the inch scale should be used for height dimensions.

D. Material Parts Survey

Purpose

The purpose of this study is to gather and analyze the dimensional data of existing materials, building parts, components and elements in an effort to determine significance. This study, therefore, concerns the accumulation of dimensional data with regard to presized and preshaped building materials and premade stock type components. Such items as form pans and channels, framing members, masonry units, decking, and panels are examples of these materials and/or components.

Three separate steps are involved. The first deals with the development of a categorical listing of building segments and materials which are dimensional in nature so that the various kinds of materials, components and/or parts can be organized in an orderly fashion. The second step involves the process of reviewing the brochures and technical bulletins of numerous manufacturers and trade associations to search out the common stock and variable dimensions. The third step concerns the organization and analysis of these data for guidance and presentation.

After a categorical listing of building segments and materials is formed, a review of technical literature will indicate various common stock dimensions. The following examples indicate the type of summary information developed.

Example I - Stock Concrete Form Pans

Material - Pressed or formed sheet metal

Types - Dome, Flange, Adjustable and Long Form

Example II - Masonry Materials and/or Systems

Materials - Limestone, slate, granite, marble, brick, tile, terra cotta and cementitious block.

Types available - Varies (small unit to large unit in slab to block shapes)

A. Summary of Dimensional Data (according to materials) inch units.

1. Limestone

Joint sizes - 1/4 and varies
Lengths - random - usually varies from 12 to 72
Heights - to conform to design - 2-1/4, 5, 7-3/4, etc.
Thicknesses - 3, 3-1/2, 4 etc.
Cut to order

TABLE III. DOME TYPE FORM PANS

DEPTH - IN.				PLAN SIZE - IN.							
D	3	4	5	W	3	4	5	L	3	4	5
6	X			20		X	X	20		X	X
8		X		26				26			
10			X	36	X	X		26			
12	X	X		30	X		X	30	X		X
14				36	X	X		36	X	X	

NO. OF DIFFERENT DEPTHS	5	3	4	5	SYMPATHETIC WITH 3, 4, OR 5 INCH BASIC MODULE
		2	2	1	
NO. OF DIFFERENT PLAN SIZES	5	3	4	5	DITTO
		2	2	2	
NO. OF DIFFERENT COMBINATIONS	25	3	4	5	DITTO
		4	4	2	

TABLE IV. FLANGE TYPE FORM PANS

DEPTH - IN.				PLAN SIZE - IN.							
D	3	4	5	W	3	4	5	L	3	4	5
6	X			10			X	12	X	X	
8		X		15	X		X	18	X		
10			X	20		X	X	24	X	X	
12	X	X		30	X		X	36	X	X	
14											

NO. OF DIFFERENT DEPTHS	5	3	4	5	SYMPATHETIC WITH 3, 4, OR 5 INCH BASIC MODULE
		2	2	1	
NO. OF DIFFERENT WIDTHS	4	3	4	5	DITTO
		2	1	4	
NO. OF DIFFERENT LENGTHS	4	3	4	5	DITTO
		4	3	0	
NO. OF DIFFERENT COMBINATIONS	80	3	4	5	DITTO
		8	6	0	

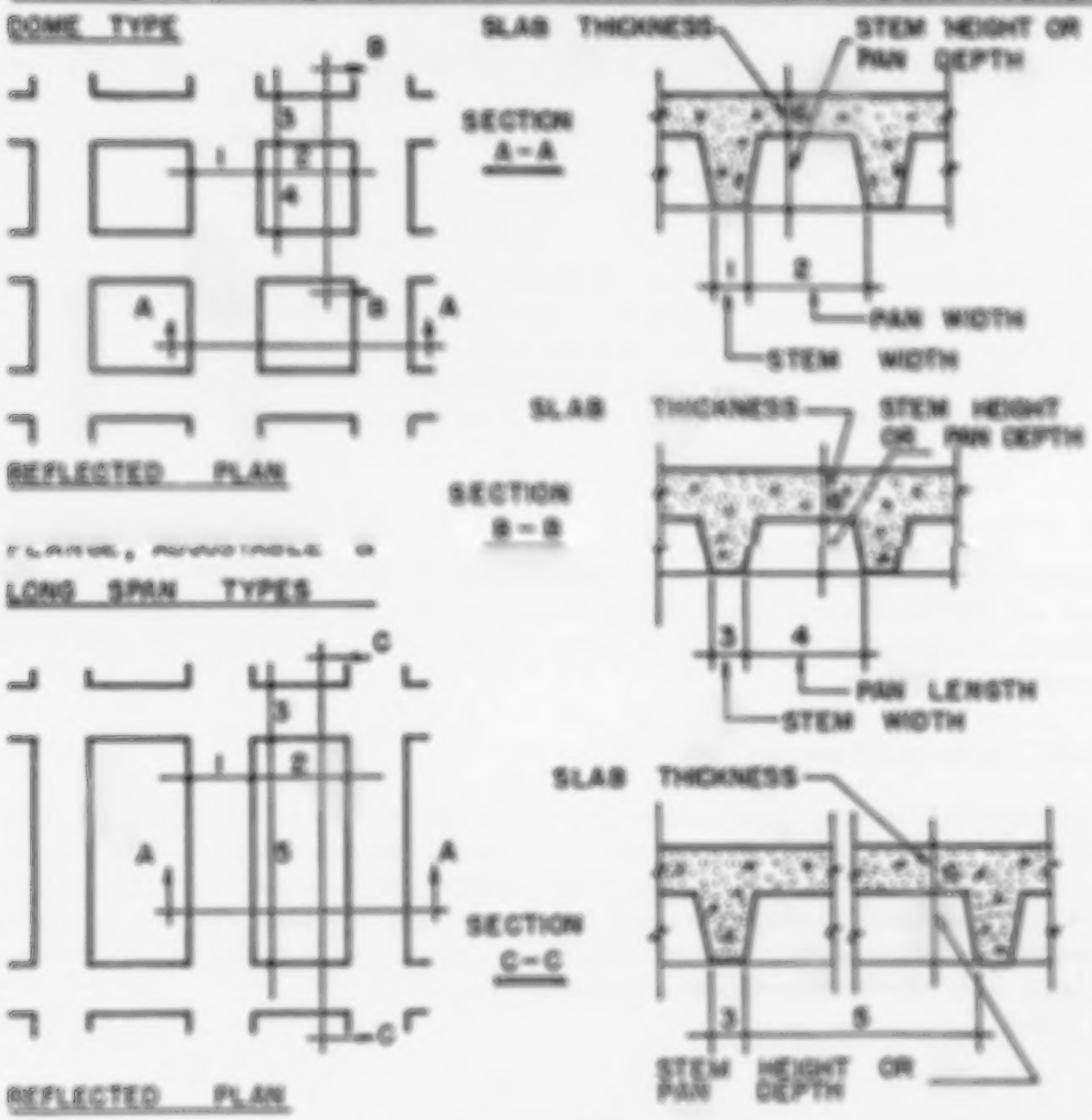
TABLE V. - ADJUSTABLE TYPE FORM PANS
(SAME AS FLANGE TYPE)

TABLE VI. LONG FORM TYPE FORM PANS

DEPTH - IN.				PLAN SIZE - IN.							
D	3	4	5	W	3	4	5	L	3	4	5
6	X			10			X	144 MAX.			
8		X		15	X		X				
10			X	20		X	X				
12	X	X		30	X		X				
14											

THIS TYPE IS FURNISHED IN ANY LENGTH UP TO AND INCLUDING 144 INCHES ACCORDING TO ORDER

FIGURE 2 DIMENSIONAL DATA - FORM PAN CONSTRUCTION



2. Slate	Joint sizes - no specific dimensional information Lengths - same Heights - same Thicknesses - same Cut to order
3. Granite - Marble -	Joint sizes - 3/16, 1/4, 3/8, 1/2 (Nom.) Lengths - depends on grade and specifications Heights - " " " " " Thicknesses - 7/8 to 3 and thicker Cut to order
4. Brick, Tile, Terra Cotta, Cementitious Block	Joint sizes - 1/4, 3/8, 1/2, 5/8 (Nom.) Lengths - 4, 8, 12, 16 (Nom.) Heights - 2, 2-2/3, 4, 5-1/3, 6, 8 (Nom.) Thicknesses - 2, 4, 6, 8, 10, 12 (Nom.)

Many masonry units in 4 above are referred to as "modular" (based on a 4 inch unit). This is understood to mean that they course out vertically and joint out horizontally to 4 inches or multiples of 4 inches, i.e. 4, 8, 12 and 16 inches depending upon material, i.e.:

2 inch units	2 courses equals 4 inches vertically
2-2/3 inch units	3 courses equals 8 inches vertically
5-1/3 inch units	3 courses equals 16 inches vertically
6 inch units	2 courses equals 12 inches vertically
4 and 8 inch units	1 course equals 4 or 8 inches vertically

Summary of Dimensional Data

The dimensional data included in Tables III and IV above indicate that a small percentage of the furnished stock sizes are sympathetic with a single basic module. The single basic module which is most frequently employed for stock concrete form pans is 3 inches.

Design and Construction Considerations

When pre-made concrete form pans are contemplated, many factors must be taken into account before the depth, width, and length dimensions can be established. Such considerations as span length, clear room height requirements, use of extra deep girders versus constant over-all construction thickness, slab or cap thickness, stem width, location of interior partitions, increment height units of partitions and walls, etc. will affect dimensional decisions.

Dimensions labeled (1), (3), and (6) in Figure 2 can be varied according to the many requirements. If a nonmodular pan not a multiple of a basic 3, 4, 5 inch module is used the dimensions of the total construction can be made modular by varying dimensions (1), (3), and (6) as required or by the multiple use of nonmodular pans. Similarly, if a modular pan is used, the dimensions of total construction may become nonmodular if no significance is attributed to modularization of detail dimensions.

The significance of design and construction considerations aside from furnished pan dimensions is important. It is significant for details to be in terms of a group of courses equalling 4, 8, 12, or 16 inches rather than individual courses, since it is possible to attain non 4-inch modular over-all dimensions even though they may not be desired. In the case of 2-2/3 inch units, any number of courses not divisible evenly by 3 will produce over-all dimensions which are non-multiples of 4 inches. Moreover, the use of non-modular basic units in certain multiple sequences may fall within 4 inch modular frames of reference.

Result of Study

The data are organized in an orderly fashion and analyzed to determine significance to the development of a system for design and construction. Dimensional information is available for a great variety of materials, products and components and the element and construction systems which result from their assembly. In addition these data are refinable to almost any desired degree. The significance of these dimensional data is important for the purpose of this research program.

The following conclusions are reached from this study:

a. Building materials, products, components and construction systems are available in a wide variety of sizes.

b. There is no single basic module applicable to the sizes available.

c. More than sufficient dimensional data has been accumulated to substantiate the fact that any system must be <u>for</u> and not <u>of</u> design and construction.

d. These data indicate the desirability of more than one basic unit.

e. The system or method must contain intrinsic dimensional flexibility.

f. Except for the important findings indicated in b, c, d, and e above, there is little significance in the relation of existing material dimensions and the system development.

g. The great variety of dimensional data obviates the value of any verification by means of the information disclosed in this study.

E. School Building Cost

The subject of this study is one which has received increasing attention, exploration, and discussion in varying degrees over the past two decades. Individuals and groups with varying interests have been concerned with educational costs because our educational policies and procedures are a bulwark of the citizenry, family, community, state and nation. In this republic with its history and future so intimately related to the individual, any other way is inconceivable.

With the public interest and support at the forefront, advances have been made to improve many levels and areas concerning both educational economy and cost. The words economy and cost, although related, have different connotations even though frequently used synonymously. When used indiscriminately, a cloud of misunderstanding surrounds the subject which leads to considerable confusion. Consequently, clarification of these terms is needed.

The term economy is understood to mean total value over the life span of a school facility. It includes initial, interim and long-term costs as required to receive maximum benefits for educational purposes. Full economy would comprise maximum value for the least expenditure. On the other hand, cost is the amount expended. Cost is often the monetary yardstick used to evaluate material and services received but by itself does not indicate or describe the value.

Since this research concerns the physical school building and more specifically the new building, the subject of over-all economic advances must be limited to building costs. For instance, in New York State, school building programs represent approximately 12 per cent of that part of the individual's tax rate required for education. This percentage figure is included only to indicate that many factors, some specific and others intangible, must be included if total educational economy is the subject of concern. Here, however, the subject is limited for purposes of relevancy.

Published cost comparisons in other areas of construction, this, however, does not obviate the need for constant vigilance and continued efforts to make further improvements for quality school buildings.

There are many cost or economic factors which cannot be overlooked when dealing with over-all economic problems of a school district. Long range programming and planning will do much to reduce the cost to a district. A more economical solution than merely measuring construction costs may be provided by such things as proper timing for land acquisition before costs rise; proper location of new sites; transportation cost studies; the optimum cost of instructional services, administration, fixed charges, and other services; and maintenance, operation, and debt service. This emphasizes the fact that there is no one segment or area by which the goal can be accomplished. A constant search and surveillance of all aspects and factors within each district will produce economy.

Purpose

The aim of this study is to prove that the use of the system of modular coordination for design and construction of school buildings will effect a reduction in cost and in time. It is expected that by developing comparative information on a factual basis, validation of the hypothesis can be achieved.

Approach

The staff for the study requested, as a part of the school sample data, detailed cost breakdowns for each of the selected examples. Requests for methods of accumulating school building costs were also made from several sources in an effort to better understand the significance of the data collected and to enable more meaningful interpretation. Various articles, reports and tests were reviewed in detail, and in addition, the Advisory Committee established a subcommittee to assist in the accumulation of information and the knowledgeable understanding of the status of school building cost data.

During the analysis, variations in the methods for deriving costs indicated that caution must be exercised regarding the validity of the data from the standpoint of comparability. Some of these variables are discussed in the following paragraphs.

Cost information is usually reported in terms of dollars per unit. The unit may be the total school plant, the building, the classroom, the pupil, the square foot of gross area, the square foot of net area, or the cubic foot. The actual number of dollars required to provide an individual school plant under a specific set of circumstances is obtained from the sums of the various contract amounts involved in the project. These dollars can be divided according to various categories such as site, building construction, mechanicals and electricals, and furnishings and equipment. The units can also be determined, but all too frequently different parameters are used in this determination. For instance, there are various requirements which [illegible] the areas to be included and how the area is to be computed. In addition, there are [illegible] factors [illegible] in significance depending upon which set of requirements is being followed. Covered walkways, roof overhangs covering paved areas, and the like if multiplied by different factors will affect the reported cost picture.

The educational specifications resulting from the decisions of those persons responsible for the facility will affect the cost picture. If out-of-doors covered walks are used for student circulation in lieu of closed corridors; if dual purpose as opposed to single purpose spaces are deemed advisable; if areas per pupil vary in classrooms, auxiliary spaces and service rooms; etc., a cost comparison will be difficult and being less comparable will, therefore, be less informative. This is particularly true as parameters become more comprehensive.

Variations in requirements by control authorities are also reflected in costs. Educational municipalities in different states come under the guidance of different

authorities depending upon their individual modus operandi. Requirements whicl vary and can contribute to further differences in the comparison of costs concerr (a) site, planning, design and construction; (b) fire and other safety requirements; (c) mechanical (heating and ventilating); (d) electrical (illumination) and (e) sanitary.

Regional, community and specific site conditions also vary. The financial status of the locale, the type of business organization utilized by the persons involved, the funding program, etc. are other varying considerations which also influence costs.

It was first thought that a few designs could be reviewed in the light of the developed system and that time and cost estimates could be accumulated to verify in part the general hypothesis of this program. After considerable study, several conclusions became apparent to challenge the validity of this approach as follows:

(1) It would be mandatory that the estimators not only gain the most intimate and detailed knowledge of all parameters of design criteria influencing each design, but also comprehend the significance and effect of the system on the designs under consideration. The possibility of accomplishing this was unrealistic.

(2) The ability to estimate accurately in order to withstand detailed scrutiny was extremely questionable.

(3) The across-the-board advantages accrued by individuals involved in a design and construction through the employment of the system could not be converted to substantiable time and cost units.

(4) The indeterminate factors involved were too numerous and unrelated to form valid results.

factual information, since the facts were either nonexistent or nondecipherable. To attempt to prove on the basis of estimates in lieu of facts would be perpetrating a major disfavor not only to this study, but also to the entire subject of the modular concept. Another approach, therefore, was initiated in an effort to support the initial contention.

This approach involved the search for various published statements, judgments and conclusions of individuals and/or groups that had studied in the same or associated area. The intention was to discover whether or not other parallel efforts would result in conclusions to support or confirm the hypothesis.

The following are selected quotations which support in part the original contentions of this cooperative research program:

Quoted excerpts from Potential Economies in School Building Construction pre-

pared by School of Architecture, Rensselaer Polytechnic Institute, Troy, New York, for the New York State Education Department - 1958.

"The Use of Repetitive Units in Planning . . . .

Conclusion: Although it is not possible to assign a comparative quantitative value to the potential economy inherent in full utilization of modular principles, there is no doubt that this is one of the most fruitful paths for future development of economies in school building design and construction. Ultimately it probably will offer more promise of economy than any other currently known technological concept."

"The Space Module Concept . . . .

Conclusion: No precise evaluation factor can be assigned to the general use of the basic space module principle but schools embodying this concept have been built at costs substantially lower than those of conventional design. The extent of savings will vary with the skill of the planner but may amount to as much as ten per cent of the total construction costs."

Quoted excerpt from Planning America's School Buildings. AASA School-Building Commission, American Association of School Administrators, 1960.

". . . A building design which offers the contractor an opportunity to use repetitive standard (material) modules permits him to make more accurate estimates of material and labor requirements and tends to reduce the over-all cost of construction."

Quoted excerpt from The Cost of a Schoolhouse, Educational Facilities Laboratory, 1960, p. 137.

". . . Modular measure has not yet taken hold in school construction - only about one school building in ten is modular - despite the savings that could job, (3) cost of designing and detailing, and (4) cost of estimating."

Quoted excerpts from the November, 1957 issue of Progressive Architecture.

"I discovered that working to a dimensional (space) module gave direction and discipline to my work, and resulted in efficiency and economy in the use of structural parts for building. I also found--and this was possibly the most important factor--that the principle of dimensional order applied to the design of a structure resulted in a quality in the work which could not be captured in any other way."

ERNEST J. KUMP, Architect

"For many years our office has produced nothing but modular buildings, based on the 4-inch increment . . . We join with the constructing contractors in attesting to the consequent modular profit this system has generated in cash for architect, contractor, and owner."

C. E. SILLING, Architect

"We recognize that universal adoption of the modular dimensioning standards can bring about some very desirable changes in design, construction, and manufacturing activities. It has been the experience of my firm in the production of modular interior partitions that a set of architect's modular drawings saves approximately 20 per cent in our engineering detailing and listing time alone. Other manufacturers can cite a similar example of cost savings. . ."

FRED M. HAUSERMAN, President
Producers' Council, Inc.
President
The E. F. Hauserman Co.

"The continuing development of prefabricated modular components is clearly essential to the future of the building industry. It will not only produce more buildings at lower cost, but will also result in substantially improved standards of building design and performance.

"It must be realized, however, that this implies more than mere production of building parts in modular sizes. To be truly successful, each building must also satisfy its own special requirements so that it meets high aesthetic standards.

"Consequently, modular components must be produced in sufficent variety of sizes, colors, and textures in order to provide architects with maximum latitude in design. Otherwise, Modular Measure could result in a spate of monotonous look-alike structures that could stifle the development in its infancy."

DAVID S. MILLER, Chairman
Producers' Council, Inc.
Vice-President for Marketing
Kawneer Company

"More and more building components will be made in manufacturing plants under controlled conditions which lend themselves to improved products with definite control on quality and pricing . . . Over-all, the elimination of cutting and fitting of all the component parts of the building, due to accurate prefabrication and standardized materials, makes it possible to get a quality building faster, so, in turn, it can start producing revenue for the owners early . . ."

C. J. NOCAR, Director, Acoustical Materials Association
Assistant to President, The E. F. Hauserman Company

". . . A logical future development in the precast-concrete industry will be modular-size framing elements, such as columns and beams for skeleton construction. Even concrete cast in place in the field may benefit from modular planning. Modular planning will permit standardization and re-use of forms, thus reducing costs of the most expensive single item in cast-in-place concrete construction."

PAUL F. RICE, Technical Director
American Concrete Institute

"For years we have manufactured building materials which have been made to modular sizes. Our experience has been that much time and effort are saved on the part of everyone concerned in the layout and construction of the building when the design is based on modular principles and modular component parts are used.

ROY C. KENDALL, Manager
Technical Services
Kimble Glass Company

". . . Coordination of dimensions of building materials and equipment is essential for the elimination of waste and the reduction of installation time, with resultant reduction of building costs. . . ."

O. C. LANCE, Secretary-Manager
National Woodwork Manufacturers Assoc., Inc.

". . . It is our opinion that the use of modular design and standards will permit economies in the actual construction operations so that the public will receive its building facilities, as executed by the contractor, at a lesser cost than otherwise would prevail."

WELTON A. SNOW, Manager, Building Division
Associated General Contractors of America, Inc.

Quoted excerpt from the September, 1958 issue of Architectural Forum article "Frank Lloyd Wright: Master of Architectural Space."

". . . Wright forever challenged the thesis that rigid, modular building can only [illegible] to more flexible building. Those who insist upon using the module as a new kind of strait-jacket do not, in Wright's view, understand the full potentialities of industrialized building."

Result

The result of the search for judgments and conclusions that substantiate the hypothesis is qualitatively affirmative. No quantitative means were disclosed, nor are they believed to be significant within the bounds of present knowledge, since actual experience involving the developed system is nonexistent.

There are economies to be gained in the form of increment cost savings, time savings and/or the obtaining of higher quality, more space, etc. for the same expenditure if the system for design and construction is utilized throughout the building industry process, that is, from planning through execution of construction.

F. Volume Study

Purpose

This study is an attempt to develop a method by which the activity requirements for a particular school facility can be translated readily into space or volume. This volume can be of a certain shape, plan area, and height depending upon the activity. The dimensions resulting from this volume can be used either as an important influence upon the development of the "design" segment of the modular system, or as an instrument for appraisal of this segment.

In the design of any space certain criteria must be satisfied. These criteria include the type of activity carried on within the space; the age and size of those occupying the space; the population; the required environment such as air-conditioning, ventilation, lighting; and the particular equipment required for the activity. If these requirements for the wide range of activities and age groups were to be identified with their specific parameters, then, for each of the various functions identifiable in a school plant, the related volume or space with its dimensional relationships might be derived. The volume (space) study is an attempt to isolate the criteria and devise a method of empirically transforming these requirements of a space activity into a particular volume.

Approach

The essence of one phase of design, to arrive at a volume and shape for a given activity area, precludes the establishment of certain preferable requirements for this activity and its peripheral uses. These requirements set the dimensional character of the space or volume created, once the activity, age limit, and population of the area are established. It is necessary to determine the space required to provide for the subactivities to be encountered, the anthropometric information, the necessary allocated equipment, the illumination requirements for the subactivity tasks, and the environmental conditions in support of the various activities within the space. The following subject diagram indicates the various design essentials contributing to or influencing the volume or the dimensional aspects of the space.

Activities

Age Group	Population	
Anthropometry	Illumination	Environment
Space	Work Levels	Airmass
Equipment	Contrasts	Vent. Circulation
Arrangement	Brightness	Air Change
	Type	

Dimensional Characteristics

The developmentsof the basic dimensional characteristics were incorporated in an example, progressing as the study advanced. The activity space selected for study is the general classroom with multiple range instruction and recitation. From an age group corresponding to grade levels of 4, 5 and 6, the 4th grade with ages 9-10 years was chosen. A pupil of this age bracket requires certain areas and volumes to perform the particular activities normally associated with the general classroom routine for this grade. These are set by the anthropometric and motion dimensional requirements.

The educational program establishes various subactivities within the main facility such as group recitation, group work, horizontal and vertical requirements, access, circulation, and teaching. Various combinations of these activities and particular student and equipment disposition determine according to population the subactivity areas and volumes required for the total classroom.

These subactivity areas and volumes are defined in terms of the pupil needs by establishing basic space units for each of several kinds of specific activity. Each unit expresses both a floor area and a volume of space as required per person per subactivity. For instance, Unit 1 representing a pupil seated, requires an area of 4 square feet and a volume of 20 cubic feet. Unit 2, for a standing-walking pupil, represents 3 square feet of area and 16 cubic feet of volume. The area in each case is multiplied by that height dimension required to accomplish the specific activity volumetrically. A summary of the basic space units applicable to this presentation is as follows:

Basic Space Unit	Subactivity	Area ft^2	Volume ft^3
1	Pupil-seated (horiz. task)	4	20
2	Pupil-standing, walking (aisle)	3	16
3	Pupil-standing (vert. task)	6	32
4	Circulation (2 passing)	7	49
6	Equipment (low storage)	6	16
7	Teacher	36	252

Several patterns of over-all and special group seating are studied. Depending upon the arrangement of the seating pattern, certain particular and special areas and volumes will result. For instance, three representative patterns are shown below. It is evident that in resolving particular seating patterns, the space representation of an area or volume basis (not on a true square or cube) requires a special unit, which is termed Basic Space Unit 5. This represents the space created by the intersection of two aisles. Three such patterns represented by unit numbers are:

A.	B.	C.
1 1 1 1 1 1	1 2 1 2 1 2 1	1 2 1 2 1 2 1
2 2 2 2 2 2	1 2 1 2 1 2 1	2 5 2 5 2 5 2
1 1 1 1 1 1	2 5 2 5 2 5 2	1 2 1 2 1 2 1
2 2 2 2 2 2	1 2 1 2 1 2 1	2 5 2 5 2 5 2
1 1 1 1 1 1	1 2 1 2 1 2 1	1 2 1 2 1 2 1

The B and C patterns show the need for Unit 5.

Other patterns of work group arrangements may be expressed as a product of the number in the group and a basic unit. Then, depending upon the particular arrangement, a work area, for example, with six pupils seated around a table would be expressed as 6x 2x Unit 1 where the number 2 multiplier is the constant indicating a specific arrangement. Utilizing the basic area and volume relationships so derived, the following program is set forth and the total area and volume computed:

Program Requirements	Population	Basis	A ft^2	V ft^3
4th Grade				
Pupil	30			
Teacher	1			
Activities				
A. Seated (5 rows - 6 pupils each)	30	30 x Unit 1	120	600
Interior circulation	30	30 x Unit 2	90	480
Perimeter circulation - 3 sides		22 x Unit 4	154	1078
B. Work Group 1 (horiz. task)	6	6 x 2 x Unit 1	48	240
Circulation		4 x Unit 4	28	196
C. Work Group 2 (horiz. task with table)	6	6 x Unit 1	24	120
Circulation		3 x Unit 4	21	147
D. Work Group 3 (vertical task)		10 x Unit 3	60	320
E. Teaching (3 units)		3 x Unit 7	108	756
F. Equipment (8 units)		8 x Unit 6	48	128
Totals			701	4065

It is obvious that the volume of the space allotted for the types of activity as determined by the above program is unrealistic. The height of 5' 9-½" for an area of 700 square feet is evidence that the volume by this factor is untenable. The floor area, however, is considered reasonable for a 30-pupil classroom with limited activities and seating arrangements.

By modifying the value of the basic space volumetric unit such that all work and circulation spaces are compatible with average adult anthropometric height requirements, the total V increases to 4699 cubic feet. This provides a 6' 8" height for a plan area of 700 square feet, the value of which is undesirable when considered in terms of the plan sizes.

Illumination

A second major influence on the dimensional characteristics of space design is the illumination requirement. Natural daylighting of the work areas is desirable. This must, however, be supplemented by artificial illumination for dark, cloudy days. The light levels at the work surfaces vary for different tasks, but also vary in recommended intensity within the same tasks. Other considerations are whether the space is to utilize unilateral or bilateral lighting, top lighting or wall lighting sources, etc.

Certain criteria are established to carry the example further in an effort to determine the influence of illumination on classroom height. For the 34 x 21 classroom, a 7 foot height of fenestration produces about 15 foot candles on the opposite wall. If 3 feet is allowed for sill height and spandrel, the ceiling height becomes 10 feet.

Greater light intensity can be achieved by raising the ceiling, thus increasing the light source area. This might, however, prove impractical for construction or cost. Translucent domes could be positioned in the ceiling at the opposite wall thereby raising the light intensity at the opposite wall area to well above 30 foot candles; or the opposite wall could have high fenestration, thereby utilizing bilateral lighting. Then again, in a single story building, the lighting source could be from a light dome patterned ceiling. In other words, adequate lighting may be accomplished by various alternative methods irrespective of a conditioned ceiling height. Illumination intensity may influence minimum heights but does not empirically set specific classroom heights. Therefore, it does not establish any important dimensional requirements for the space insofar as this study is concerned.

Air Volume and Supply Rate

A third major dimensional influence on the proportioning of educational volumes or space is the environmental conditioning for this space. More specifically, air volume and rate of air change are important considerations in providing an adequate working environment for the particular tasks to be performed. Certain activities require a minimum or optimum number of air changes per period of time and volume of air per person.

For the assigned activities within this space, the following values are recommended:

Elementary school children

Air Space Per Person	Outside Air Supply
100 cu. ft.	29 cfm.
200	21
300	17
500	11

200 cu. ft. minimum air space per sedentary adult
15 cfm. minimum outside air supply per person

Since it is recommended that at least 15 cubic feet a minute of outside air be provided per person and since each sedentary adult requires at least 200 cubic feet of air, the mass of 200 cubic feet per person is selected for the example. On this basis, thirty pupils and one teacher require 6200 cubic feet of volume. Using the same floor area of 700 square feet, the volume requires a height of approximately 9 feet. If, however, the circumstances were such that the 300 cubic feet value with its related outside air supply of 17 cfm. had been selected, the required classroom height would be over 13 feet. Thus, it is obvious that the criteria of design is the significant item rather than the recommended values of air volume and air change.

Conclusions

The volume (space) study attempts to define specific design controls which might set the dimensional relationships of the variety of educational spaces for the normal range of activity use. At the outset three basic items were thought to provide specific dimensional control. These items were the anthropometrics of the age groups and the equipment and circulation requirements of the activities, the illumination requirements, and the air volume and circulation values required for environmental control.

By a rather detailed and illustrative example carried through the three stages and summarized above, it is evident that this method is not sufficiently definitive to justify the assumption that spaces can be conceived or defined solely upon this basis. For these reasons the volume study was terminated.

3. BASIC RESEARCH AND DEVELOPMENT OF THE SYSTEM

A. Introduction

In this section five studies are described which were performed during the second major task, namely, the research and development phase. These studies are concerned with the advance investigations and analyses which resulted in the tentative system.

The first study is entitled "Number Relations." It is obvious that the study of number relations and the development of a resultant usable pattern is fundamental to the over-all study of a dimensional reference system, since this, when accomplished, will create an index for dimensional control and, depending upon number content, will determine dimensional limits. The number pattern is described briefly and the companion tool, the number combination tables, is illustrated in Part B of this section.

The second study, "Modulation," concerns the development of a dimensional linkage technique which can be used to relate the several and varied parts of the entire building process. This includes the positioning of building elements defining the activity spaces; the locating of material element systems, components and parts within building elements; and the referencing of these to appropriate planes.

The next study, entitled "Proportion," is of singular significance. Since proportion is a visual art, it is an indispensable adjunct of form and aesthetics, which are inseparable from function and beauty. The study of proportion includes such subjects as its relation to present-day architecture and its influence on a dimensional system. Proportion is related to design whether it be of buildings, elements, material parts or construction aids. It does not concern construction per se. The neglect of proportion is synonymous with the neglect of aesthetic design.

The fourth study concerns planning procedures and involves the development of techniques which will relate these procedures and the segments of the dimensional system. Of primary concern are such subjects as modulation of the plan to aid in the dimensional referencing of functional areas and to prepare for subsequent element and material modulation, planer concepts for building elements and planning tolerances.

The fifth study involves building elements and the items of dimensional significance in connection with their design. Here the relation between the dimensional system segments and elements of buildings were reviewed. The procedures of modulation and correlation were studied as were the possible methods of coordination.

B. Number Relations

Introduction

The dimensional relationship between building spaces, building elements, assembled building units and/or material component sizes is in part dependent upon the set relationship between their respective dimensions which are many and diverse. The purpose of the development of the number pattern and combination tables is, therefore, to create an index for dimensional control which will become the common basis of number relations for the total system.

Development

Development followed a background search and study of number patterns devised for similar purposes by others. Criteria requirements to be met by the index for dimensional control were then determined. The index must:

- not be numerically restrictive nor limited in range,
- be usable with all scales, i.e. inch, foot, yard, centimeter, meter, decimeter, etc.,
- satisfy mathematical operations required or involved in normal building design,
- be compatible with modular principles and processes, and
- be simple and easy to read.

None of the existing patterns reviewed satisfied these requirements.

Since the background study indicated that the pattern should contain the modular coefficient 4, the vertical base line of the pattern was set as follows:

1
2
3
4

In addition, the numerical sequence expressing the arithmetic series and rigid grid of the coefficient 4 was incorporated thus:

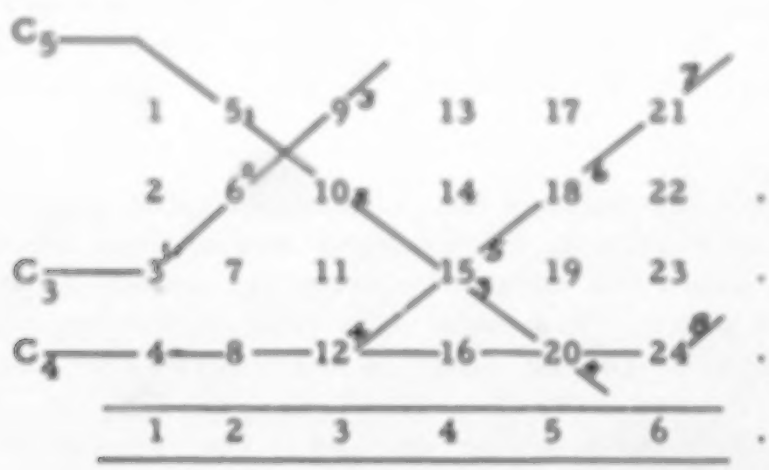
1									
2									
3									
4	8	12	16	20	24	.	.	.	.

The fact that the system under development should not be dimensionally limited infers that the number pattern contains all numbers. Therefore, the remaining natural order of numbers was added and the pattern was established:

1	5	9	13	17	21
2	6	10	14	18	22
3	7	11	15	19	23
4	8	12	16	20	24 . . . .

Parallel studies conducted within the project indicated a repeated use and compatibility of the multiples of 3 feet, 4 feet, and 5 feet to school construction. The numbers 3, 4, and 5 became basic coefficients. Numerical sequence expression lines for the coefficients 3, 4, and 5 were added so that the pattern readily expressed each coefficient's arithmetic series of rigid grid sequence. It should be noted that numbers located at the intersection of expression lines indicate like products achieved with different coefficients. For instance, the number 15 is located at the intersection of the expression lines for C_3 and C_5; therefore, 15 is the product of the different coefficients 3 and 5.

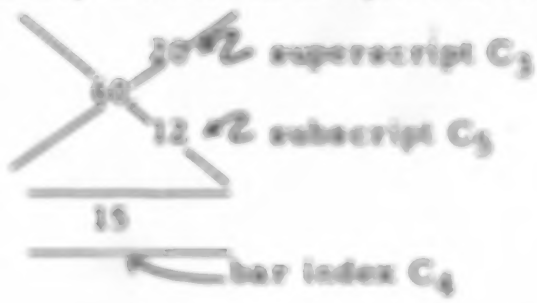
In order to facilitate readability regarding the number of basic coefficient units contained in a particular pattern number, multiple indexes were added. For clarity, two representations were found desirable. First, the bar below the pattern was added to indicate the multiple indexes for the basic coefficient 4; thus, the pattern number 8, directly above the coefficient 4 index number 2, contains 2 units of coefficient 4. Second, the multiple indexes for basic coefficients 3 and 5 were added and are identified by superscripts and subscripts respectively which are located to the right of the pattern number and each aligned with its expression line; thus, the pattern number 15 contains 5 (superscript) units of coefficient 3 and also contains 3 (subscript) units of coefficient 5.



The developed number pattern was then expanded to 100 as a convenient numerical range. The finalized pattern is shown as Figure 3.

Number Pattern Comprehension

The coefficients related to any given number are easily discernible. As an example, the expression lines of the coefficients 3, 4 and 5 intersect pattern number 60. This indicates that it (number 60) can be achieved by multiples of each of the basic coefficients (3, 4 or 5). As shown below; the number 15, in the bar and directly below 60, is the multiple index of coefficient 4. Therefore, 15 x 4 = 60; also the multiple index number 20 (superscript) of coefficient 3 indicates that the product of the multiple index and the basic coefficient equals the pattern number, i.e. 20 x 3 = 60. In addition, the multiple index number 12 (subscript) of coefficient 5 when multiplied similarly results in the pattern number, i.e. 12 x 5 = 60.



Additive combinations also may be derived. Reference to the top example Figure 4 shows that the multiple index of coefficient 4 for the number 60 is 15. This multiple index may be divided into whole integer parts. Thus, index 15 may be divided into 6 and 9. Over index 6 is pattern number 24. Similarly, over index 9 is read 36. Since pattern numbers 24 and 36 are intersected by expression lines for both coefficients 3 and 4, the following results are discernible, i.e. 24 + 36 = 60 or $6C_4 + 12C_3 = 60$ or $8C_3 + 9C_4 = 60$.

Other additives of 60 representing multiples of coefficient 4 may be derived by taking any other additive parts of 15. The middle example shows that indexes 5 plus 10 indicates 20 + 40 = 60. In the example at the bottom of the page, indexes 4 plus 5 plus 6 indicates 16 + 20 + 24 = 60, etc. Moreover, on the other multiple expression lines, passing through 60, the multiple index for coefficient 3 is 20 and for the coefficient 5 is 12. Thus, 20 and 12 may be similarly divided into parts for other additive numbers which are multiples of their respective coefficients that total 60.

This also holds true for any number not on an expression line, i.e., a non-multiple number. Reference to Figure 5, top example and number 34 shows: the multiple index of coefficient 4 below the column containing number 34 is 9. Unit 9 divided into two parts gives 4 and 5. One additive is read on the expression line for coefficient 4 over index 4, i.e. 16; the other is read in the line containing the pattern number 34 and in the column over the other index, 5, i.e. 18. Thus, over index 4 is the number 16, over index 5 in line with 34 is the number 18. Therefore, 16 + 18 = 34. The middle example shows that this could have been reversed as follows:

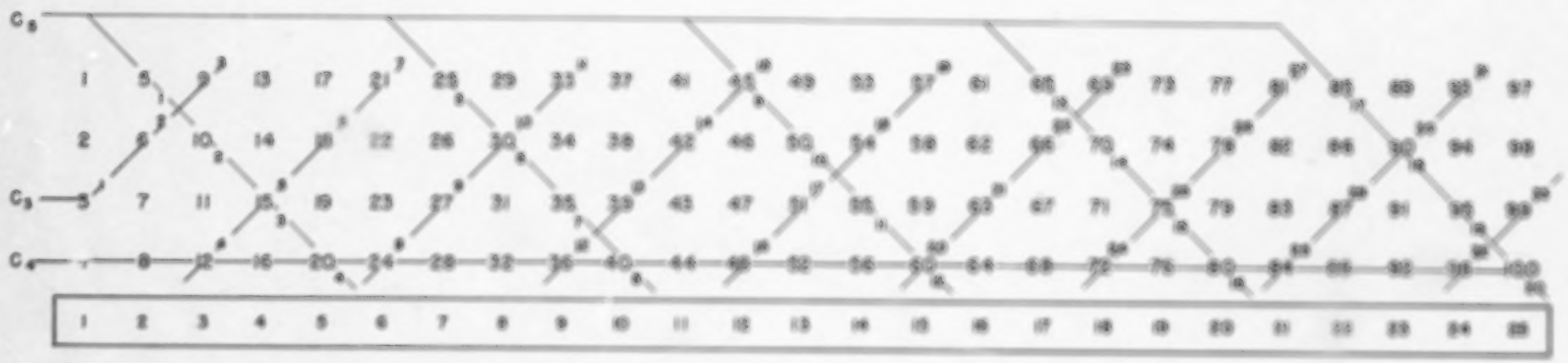


FIGURE 3 SwRI NUMBER PATTERN

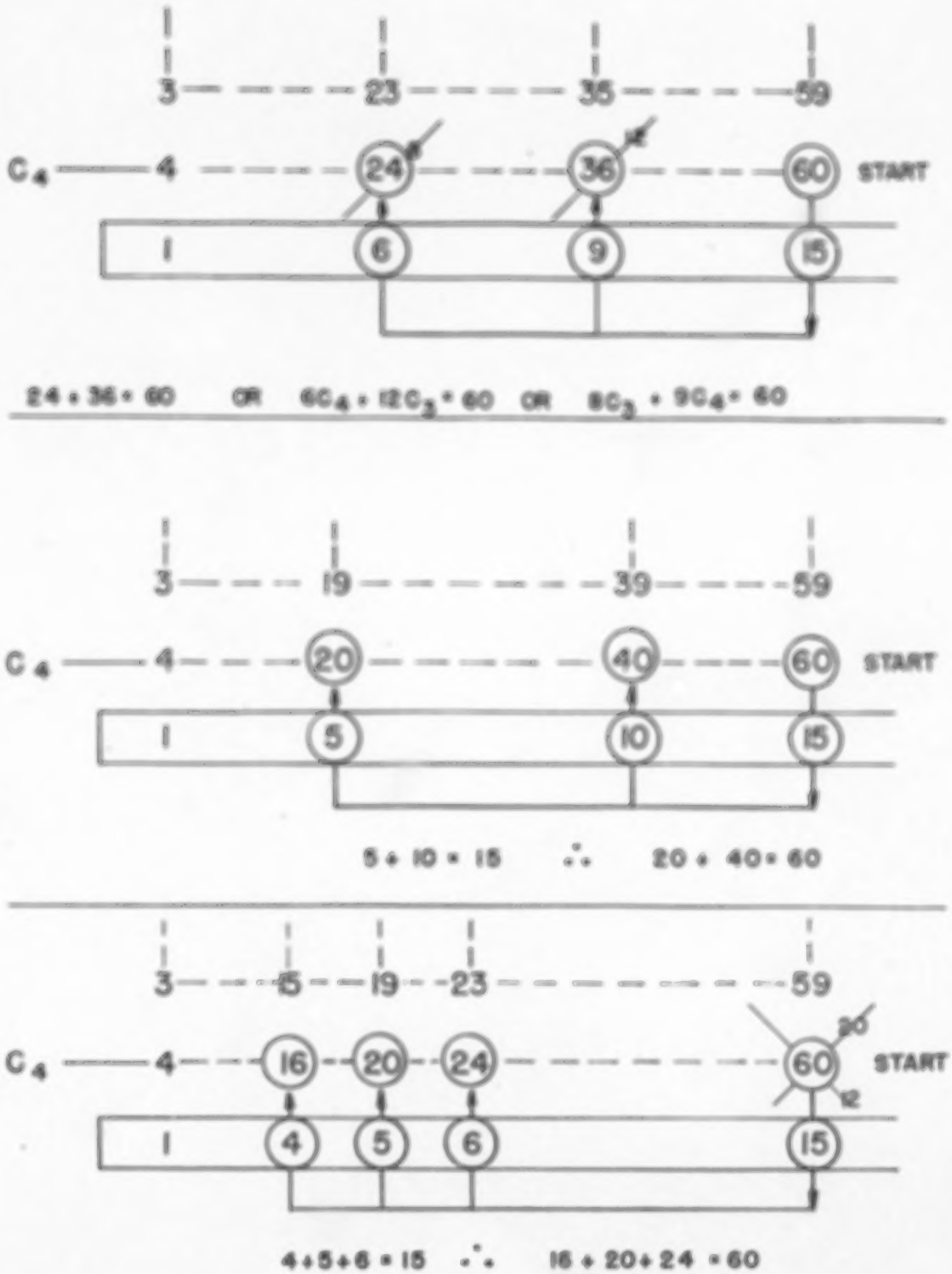


FIGURE 4 NUMBER PATTERN EXAMPLES

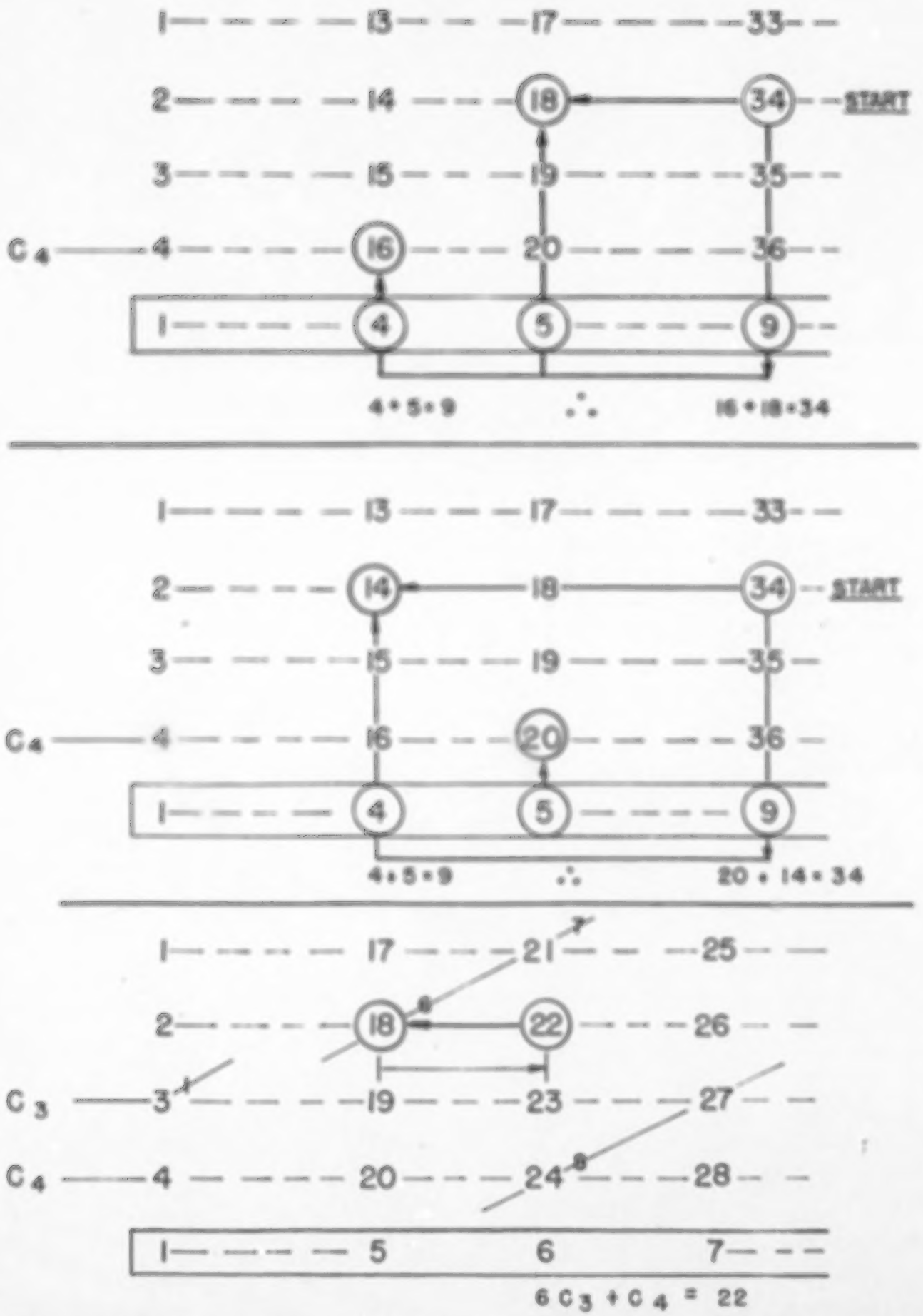


FIGURE 5 NUMBER PATTERN EXAMPLES

over index 5 is the number 20, over index 4 and in line with 34 is the number 14. Therefore, 20 + 14 = 34.

The composition of nonmultiple numbers is also discernible to the nearest coefficient multiple and its related unit necessary to achieve the particular numerical composition. Reference to the bottom example and number 22 shows that appearing directly to the left of pattern number 22 is the number 18 which is expressed as a multiple of coefficient 3 and indexed by 6. Moving one column horizontally to the right indicates the inclusion of one C_4. Number 22 can be made up of six $(C_3)^5$ and one C_4. Therefore, $6C_3 + C_4 = 22$.

Doubling and tripling a number is accomplished by doubling or tripling the multiple index and reading the product from the number pattern. Figure 6 top example indicates that number 12 is on the coefficient 4 multiple expression line; the index is 3; doubling 3 is 6; over this index read the double of 12 which is 24. Tripling index 3 equals 9; over this index 9 is 36, which is the triple of 12.

Division without remainder can be accomplished by utilizing the multiple index numbers. The middle example shows that if one-third of 60 were required, one-third of the multiple index number, 15, is taken, which is 5, and the number above, 20, is the answer. Similarly for unequal divisions, giving additives, as shown in the bottom example, the two largest nonequal additives, 28 and 32, would be read above the corresponding coefficient 4 multiple indexes, 7 and 8, respectively. Since 7 + 8 = 15, 28 + 32 = 60.

From these examples it is evident that the versatility of this pattern is satisfactory to modular application. Moreover, it contains the natural order of numbers which provides an unrestricted numerical capacity. This quality makes it possible to discern readily the relations of one number to any other number for purposes of modular coordination. The numerical capacity of the pattern, therefore, will allow complete dimensional freedom.

Development of the Number Combination Tables

The number pattern expresses the relations of the basic coefficients (3, 4 and 5) to all numbers. It indicates different ways that the basic coefficients make up particular numbers. These are termed combinations. Naturally, one must become familiar with the pattern to be able to discern several combinations for a particular number. As the pattern numbers increase, the number of possible combinations also increase. The extraction of all possible combinations becomes a tedious and difficult task. A companion tool was developed, therefore, to provide easy identification of these combinations (two are shown below). This tool is the number combination tables.

All possible combinations of the basic coefficients 3, 4 and 5 were derived for each pattern number 12 through 100. The data were arranged according to the total number of units and the number of units for each basic coefficient in each combination. Examples are as follows for pattern numbers 28 and 29:

#28

Number of Units	Basic Coefficients		
Total	3	4	5
6	0	2	4
	1	0	5
7	0	7	0
	1	5	1
	2	3	2
	3	1	3
8	4	4	0
	5	2	1
	6	0	2
9	8	1	0

#29

Number of Units	Basic Coefficients		
Total	3	4	5
6	0	1	5
7	0	6	1
	1	4	2
	2	2	3
	3	0	4
8	3	5	0
	4	3	1
	5	1	2
9	7	2	0
	8	0	1

C. Modulation

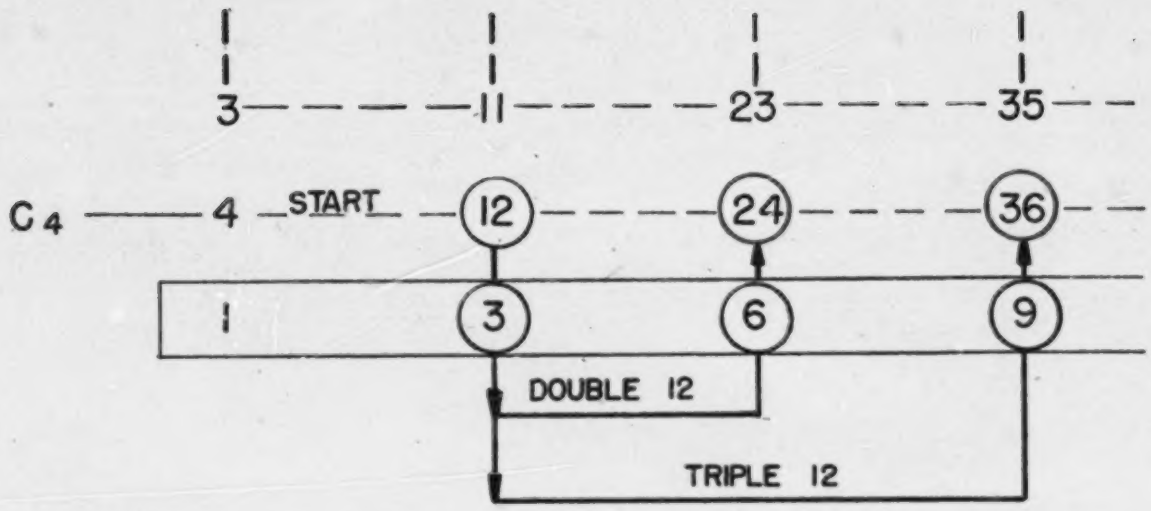
Introduction

The planning and design phases of a school building program, the composition of building elements and the job site placement of materials comprising the elements require dimensional control to satisfy modular principles if construction efficiency is to result. The purpose of this control is the predetermination of dimensional order between the building spaces, building elements and the various presized units. The technique by which this predetermined order is attained within the developed system has been termed modulation. Thus, modulation is the act of dimensionally relating in an orderly fashion the several and varied parts of an entire building program.

Development

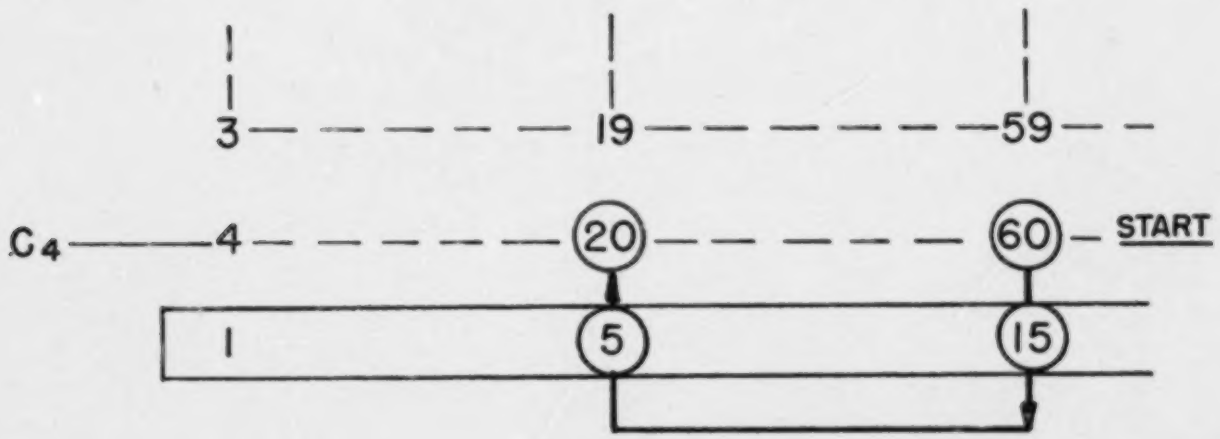
The planning of a building involves certain procedures which are concerned primarily with spaces, activities and their interrelation from the standpoints of function, circulation, etc. More frequently than not specific dimensional requirements are of secondary import. Although the planners are not primarily concerned with dimensional details, the over-all consideration of dimensions is a natural part of the analysis process.

Planning, a part of the preliminary design effort, establishes to a reasonable degree the disposition of spaces, elements and materials comprising the physical building. After approval, the process continues through the detailing stages to the point where contract drawings indicate what is to be constructed to meet the needs of the educational building program.

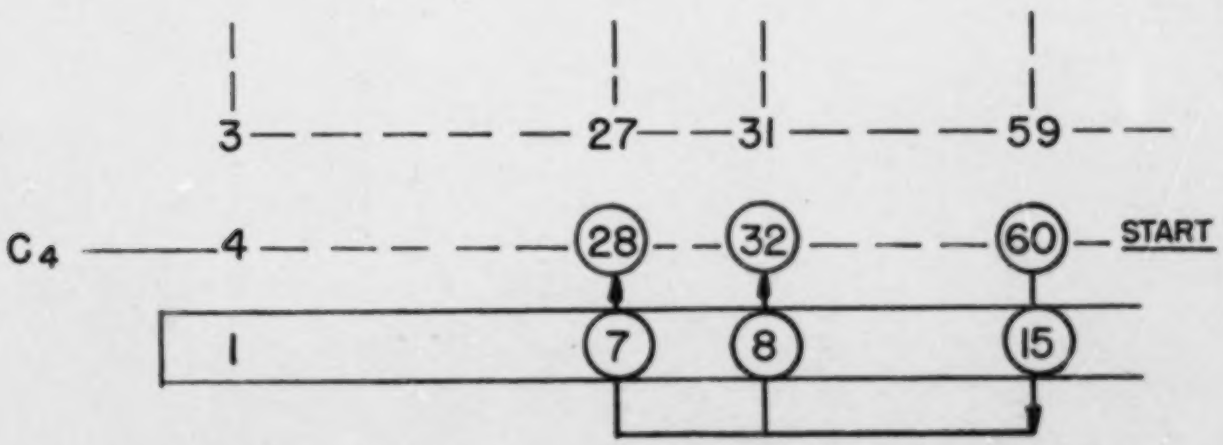


2 x 3 = 6 ∴ 2 x 12 = 24

3 x 3 = 9 ∴ 3 x 12 = 36



$\frac{1}{3}$ OF 15 = 5 ∴ 20 = $\frac{1}{3}$ OF 60



7 + 8 = 15 ∴ 28 + 32 = 60

FIGURE 6 NUMBER PATTERN EXAMPLES

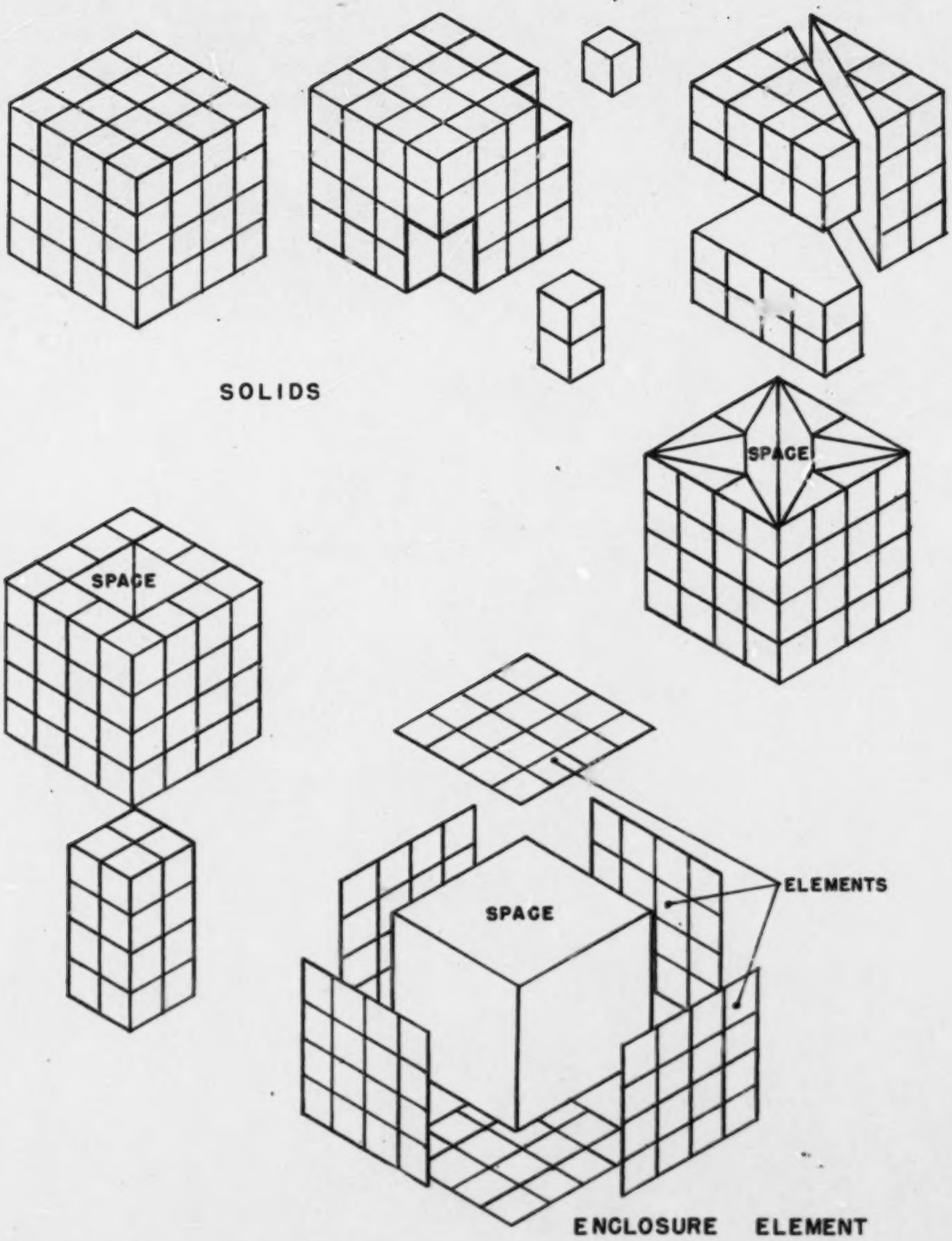


FIGURE 7 BUILDING VOLUME CONCEPT : SPACE VS SOLID

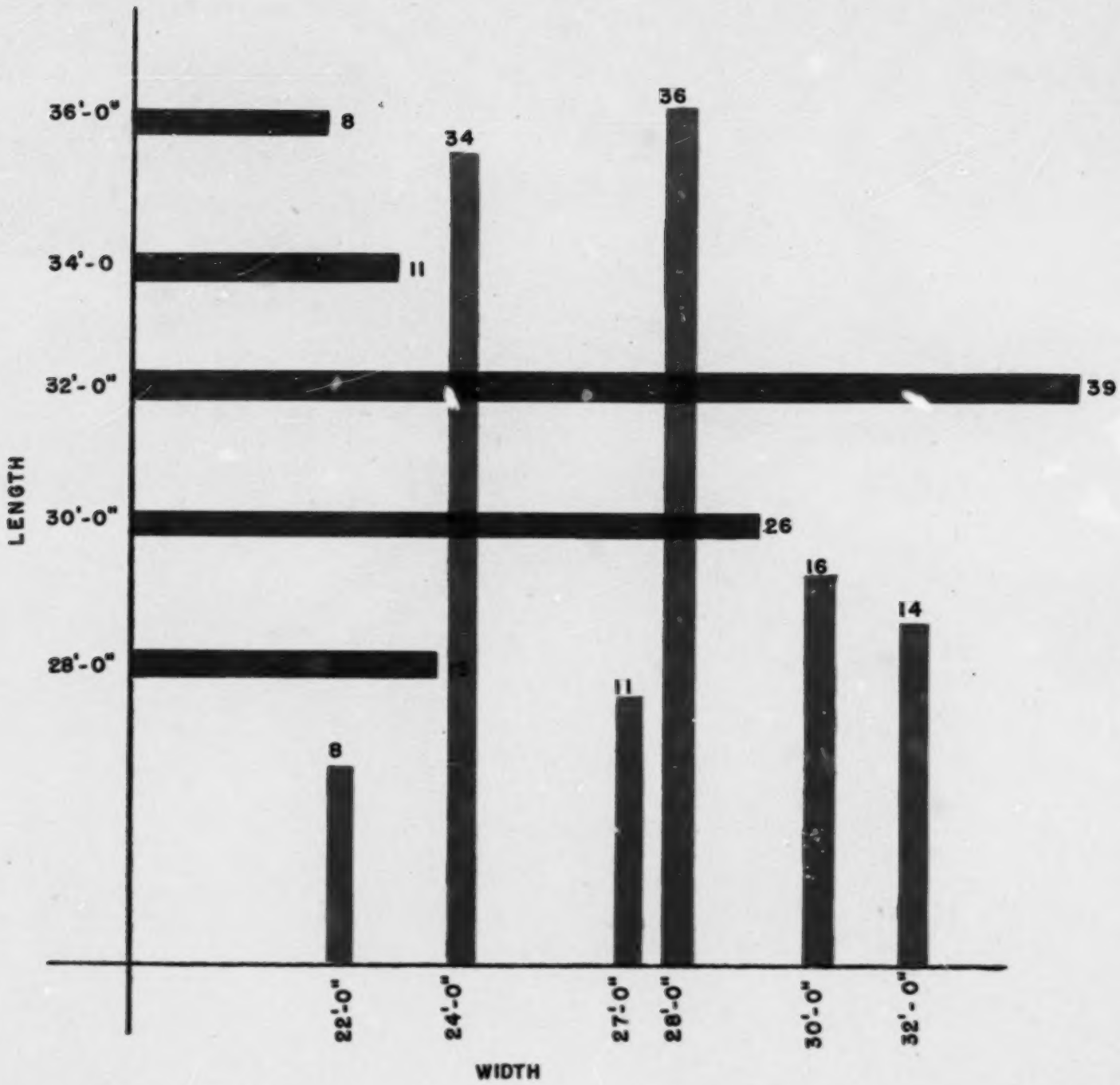


FIGURE 8 GREATEST FREQUENCY OF CLASSROOM DIMENSIONS FROM SCHOOL SAMPLE

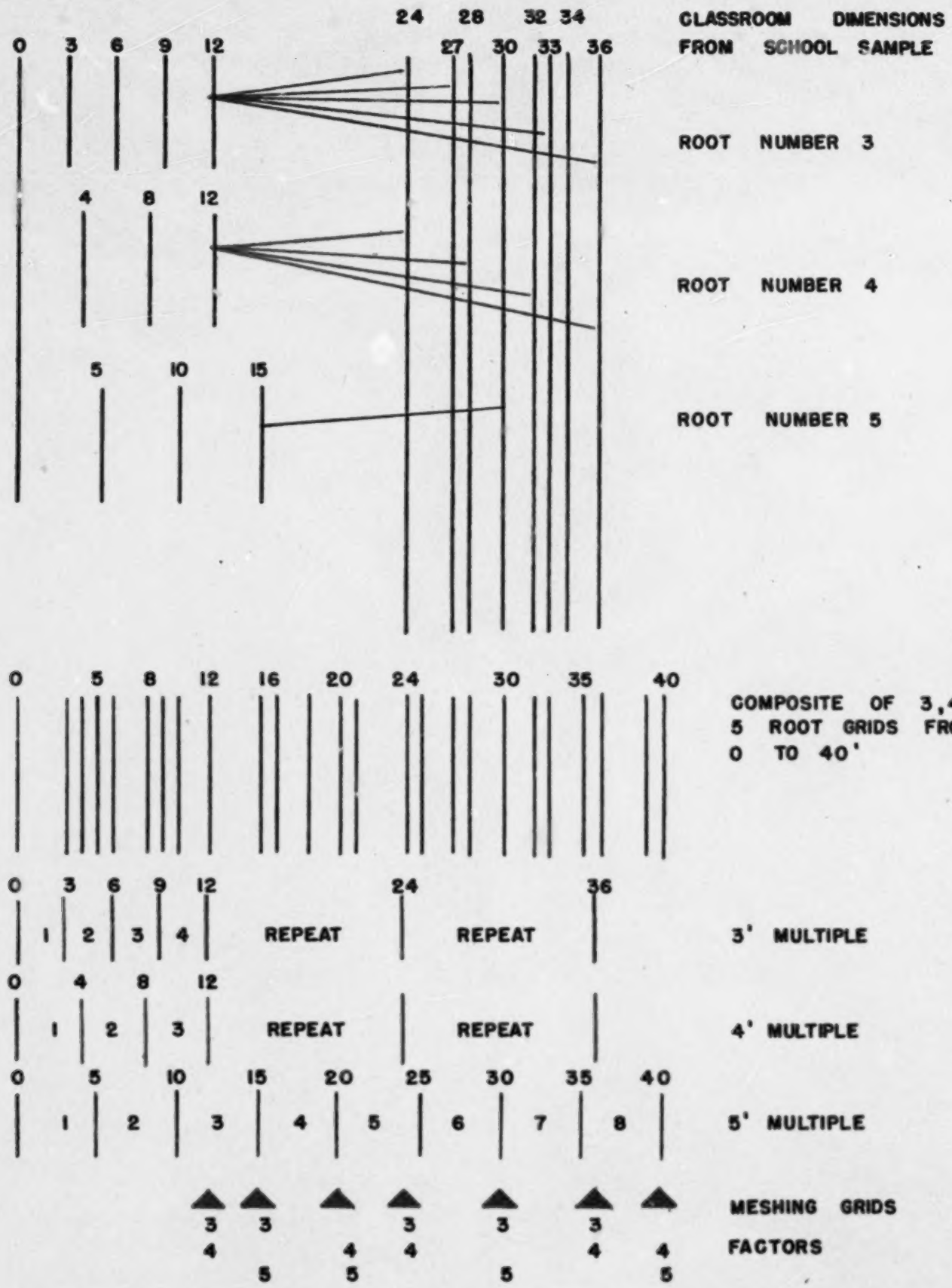


FIGURE 9 TRIAL GRID LINE SPACING

Since this natural course from concept to detail design is the process to which the technique of modulation must be not only acceptable but also useful, the development started with the study of educational spaces and spatial relationships. A school building is not a solid, but comprises articulated spaces defined by a series of enclosure elements made up of a variety of materials. Where no building elements or component materials exist or combine, the air spaces, voids, and the like are of little or no concern to modular coordination. What is important are (1) the size, shape and location of the building elements defining the various activity spaces, and of the materials comprising them and (2) the positioning and junctioning of one or more of these.

Further, the school building, although not a solid, comprises a certain mass (a group of interrelated volumes) which has one significant bearing upon modulation. The size of the mass determines the size of the dimensional or scalar index. The scaler index forms the basis for the mechanics of modulation.

With the exception of the part played by the mass of a building in determining indexes, modulation is based solely upon planer and linear concepts. For example, a building element such as a wall, according to the particular design and the materials selected, is modulated vertically and horizontally in elevation within the plane parallel to this element. Its thickness is modulated within a plane at right angles to the elevation plane, usually a plan section. The positioning of this element is also referenced linearly on the same plane as the thickness. Modulation results in a composition of one or more grids which represent the dimensional characteristics of the wall element. Other elements may be modulated similarly. The grid patterns of all enclosure elements provide the means for creating dimensional order between these elements, materials, and the planning areas.

From the study of dimensions in the school sample study, the frequency of classroom width and length dimensions and the particular intervals at which these dimensions occurred were determined. It was evident that there was high frequency in the following lengths and widths:

Length - feet		27	28	30	32	33	34	36
Width - feet	24	27	28	30	32			

It was clear that with the exception of the 34 feet, the dimensions are either multiples of 3, 4, or 5 feet and both 3 and 4 feet and 3 and 5 feet. Thus, if expressed as a 3-4 foot combination grid pattern, the classroom dimensions would coincide with the grid lines. A repetitive grid of this order points up several important factors and considerations which are valuable for modulation development. The pattern repeats itself at every twelve-foot interval.

The pattern	0,	3,	4,	6,	8,	9,	12
is the same for	12,	15,	16,	18,	20,	21,	24
and the same for	24,	27,	28,	30,	32,	33,	36

since the repetitive series is basically two superimposed rigid grid patterns (one the multiple 3 and the other the multiple 4).

At particular locations on the superimposed grids, the two systems or grid patterns mesh. This occurs in any system at the lowest number whose factors are roots of the basic grids forming the pattern. In this instance it is 12 (3 and 4 roots). It also indicates that the system is repetitive on the 12 unit interval.

From this sample study, it is evident that a single root repetitive grid system (the 3, 4 or 5 foot) is extremely restrictive. Unless elements fall in multiples of the basic root, they are not compatible with the grid pattern. This condition is untenable as no design should be restricted to dimensions which are merely multiples of a single root, nor should it be limited to a rigid pattern in space planning. In other words, the grids must express the construction and, at the same time, satisfy space requirements without compromise.

Progressing further with the sample study, it becomes apparent that the additive quality can be employed to obtain a greater variety of grid patterns. This increases the potential of meshing grid lines over that obtainable by pure multiples of a single root. This also gives rise to the possibility of grid composition based on the product of the dimensional index and the numerical coefficient.

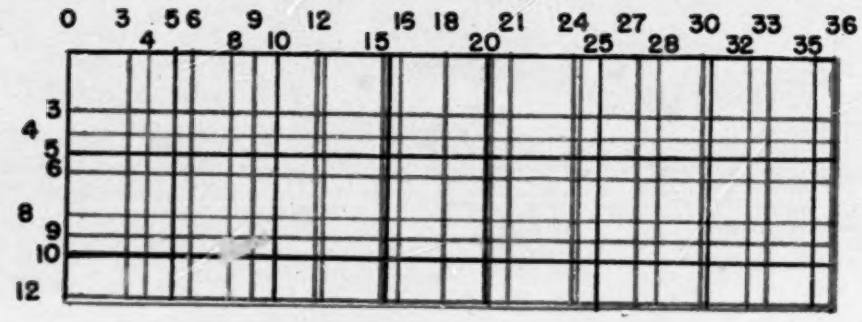
The development of modulation methods to insure as broad an application as practicable and utilizing multiples, additives, and combinations of these, requires the creation of a versatile number pattern with subsequent number combination tables. These tables provide the various integer coefficient relations necessary for modulation. The use of these coefficient relations enables the designer to modulate to the dimensional system without compromising the design solution.

The selection of the scalar index depends on which part of the design is to be modulated. The index may be any unit of length -- the inch, decimeter, foot, meter, etc. If applied to site planning, it might be large multiples of feet or meters. When modulating the over-all building and even the individual activity area, the index would probably be in the foot or in the 5 meter range, or small multiples of each. In detail application, the inch and decimeter would be appropriate indexes.

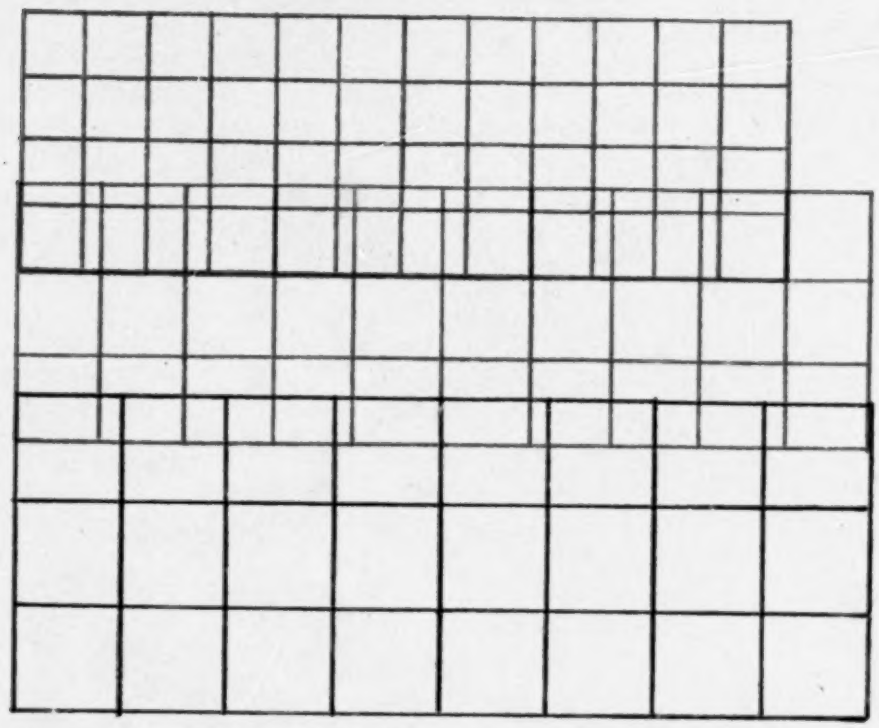
In this modulation study various methods of modulation were devised, varying in intricacy according to the complexity of the particular building design. Application techniques, however, remained common regardless of the method.

It became apparent after many trials that these could be grouped into two basic methods called "Rigid Modulation." The first is represented by grid compositions consisting of squares or rectangles where the geometry is formed by the use of a single selected linear unit in both directions or by the selection of two linear units each used in its own direction. Thus, the grid line spacing is a constant in both or in each of two directions. The second can also be represented graphically by grids but here the spacing between grid lines is not constant in at least one direction and may vary in both directions.

This study of modulation and the development of the two methods of modulation present specific innovations which provide certain "missing links" to the modular concept as follows:



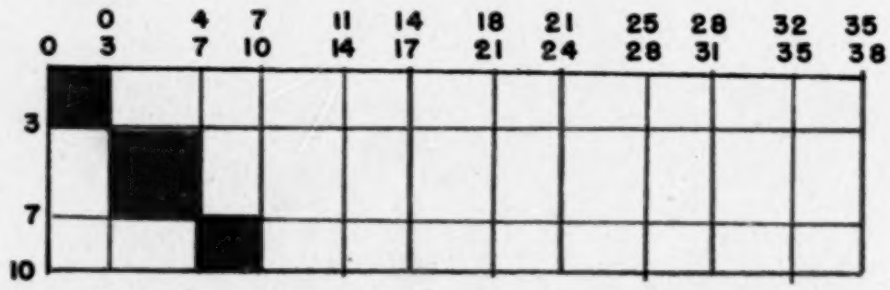
MULTIPLES



M_3 MULTIPLE GRID

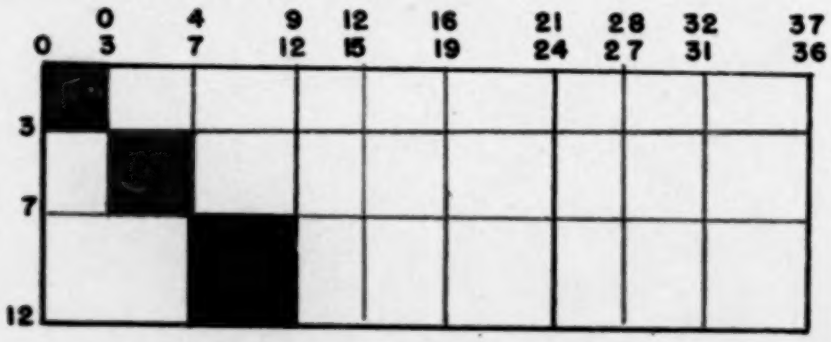
M_4 MULTIPLE GRID

M_5 MULTIPLE GRID



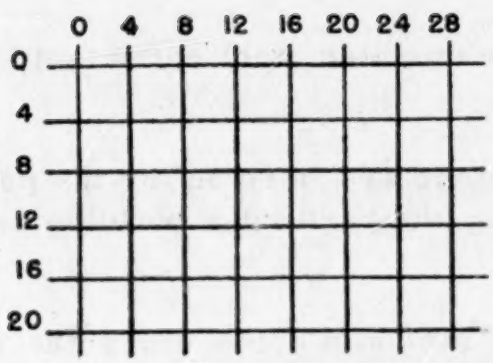
ADDITIVES

3, 4, 3, 4 ADDITIVE

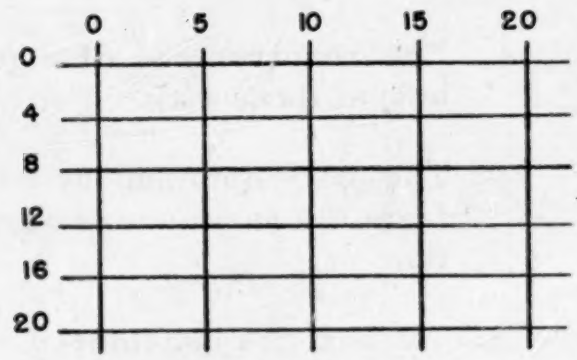


3, 4, 5, 3, 4, 5 ADDITIVE

FIGURE 10 GRID COMPOSITION

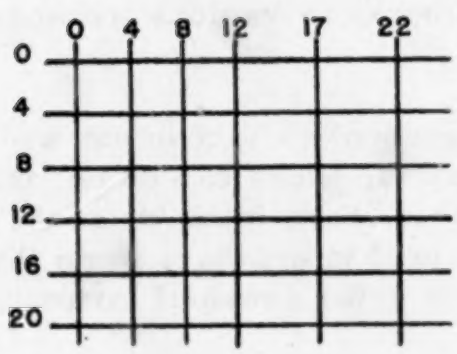


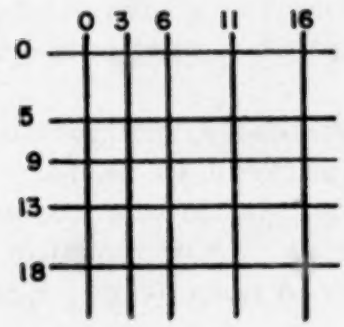
GRID LINE SPACING EQUAL IN BOTH DIRECTIONS



GRID LINE SPACING EQUAL IN EACH OF TWO DIRECTIONS

GRIDS REPRESENTING RIGID MODULATION





GRIDS REPRESENTING COMBINATION MODULATION

FIGURE 11 GRID COMPOSITION

a) The employment of more than one basic unit provides the opportunity for the combination modulation method which incorporates the features of both multiples and additives.

b) The requirement of rigidity is obviated and conversely provides inherent flexibility.

c) The grids obtained by either method are derived for the purposes of and from the parameters surrounding the particular building design in question.

These innovations are considered to be of utmost import since the designer thus may compose specific grids to represent the problem rather than by trying to force the design to an unrelated grid or by merely superimposing an unrelated grid pattern over a design and thereby impose dimensional restrictions.

D. Proportion

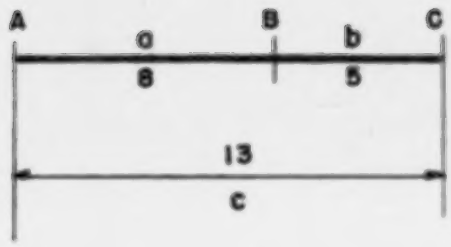
Proportion is one of the fundamentals or essentials of design, and is the foundation for composition, i. e. the method of relating or unifying compatible and contrasting elements. Its use supports organization and order and assists in determining the sizing and positioning of the elements in various arrangements to accomplish a particular aesthetic effect.

Empirically, proportion belongs to form as opposed to content and requires the comparison of parts. Where there are no parts, there can be no proportion. Although the forms do not have to be compatible, they must be of the same kind of species, as proportion is the relation of one part to another, or to the whole in respect to magnitude, quantity or degree of a selected genus of forms.

Purpose

The purpose of this section is to review the importance of proportion as related to architecture, accenting what is called composition. For some time there has been a conscious effort to achieve harmony and rhythm in architectural composition. Whether by the use of number combinations, geometrical ratios, proportionate means, or anthropometric scales, the attempt is to proportion, relate and unify the rhythmical or contrasting material elements and parts into an aesthetically acceptable design. This effort is even more purposeful and challenging today with the ever-increasing variety of machine-fabricated materials and the decreasing availability of artisan crafts.

The relation of parts of similar species may be grouped into three distinct categories: line, area, and mass. A line may be proportionate or disproportionate to another line or series of other lines. One area may be proportionate to another area or to the whole area if the comparative areas are of the same genus: rec-



$\frac{AB}{BC} = \frac{a}{b} = \frac{8}{5}$ RATIO

$8 \div 5 = 1.6$ PROPORTIONATE MEAN

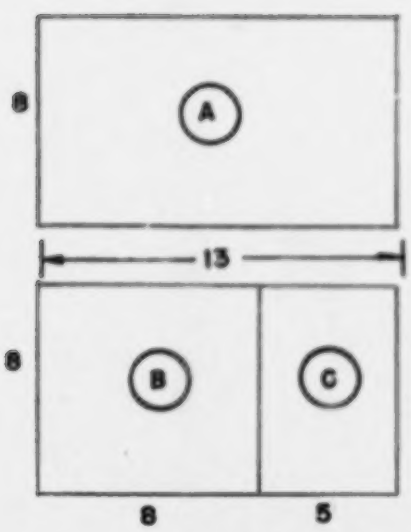
$\frac{a}{b} = \frac{8}{5} = 1.6$ ϕ

$\frac{c}{a} = \frac{13}{8} = 1.62$ ϕ

$\frac{c}{b} = \frac{13}{5} = 2.6$ ϕ^2

$\frac{a}{c} : \frac{b}{a} = \frac{8}{13} : \frac{5}{8} = 1:1.6$

AC ~ AB PROPORTIONATE



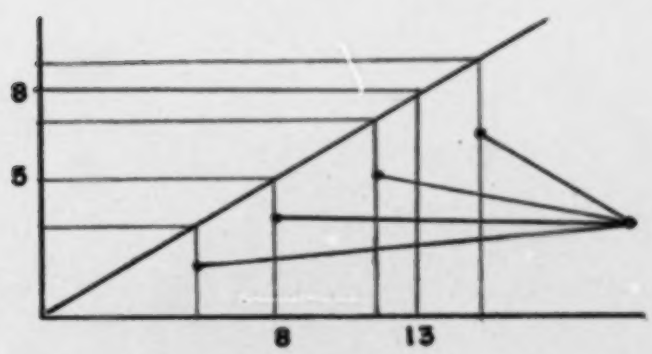
(A) $\frac{13}{8} = 1.62$

(B) $\frac{8}{8} = 1.0$

(C) $\frac{8}{5} = 1.6$

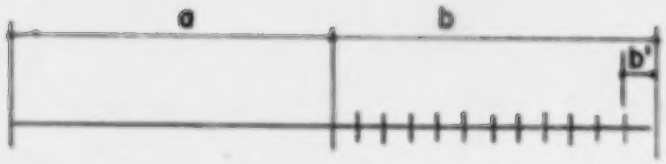
(A) : (C) $= \frac{13}{8} : \frac{8}{5} = 1.6$

(A) ~ (C) PROPORTIONATE



PROPORTIONATE RECTANGLE
1 : 1.6

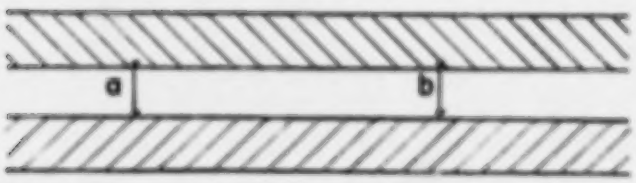
FIGURE 12 PROPORTION: GEOMETRIC



GEOMETRICAL PROPORTION a:b = 1:1

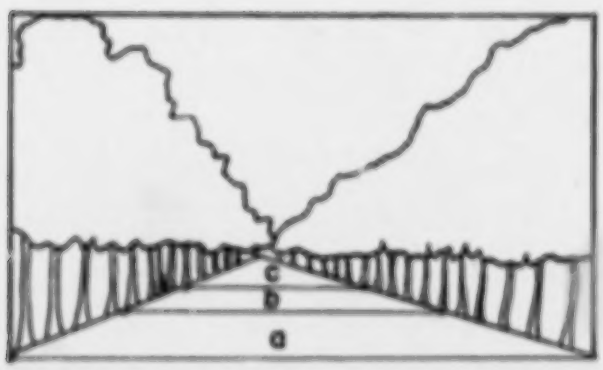
VISUAL PROPORTION a:b = 1:1 + b'

b APPEARS > a



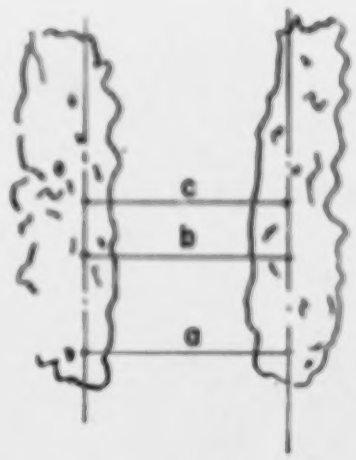
GEOMETRICAL a = b

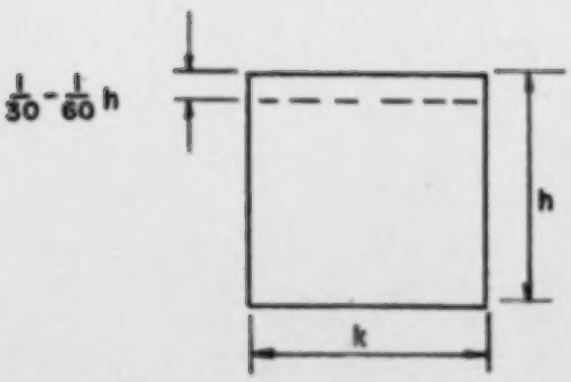
VISUAL b > a



GEOMETRIC a = b = c

VISUAL a > b > c





SQUARE

GEOMETRIC h = k

VISUAL h > k

FIGURE 13 PROPORTION: GEOMETRIC VS VISUAL

tangles to rectangles, circles to circles, trapezoids to trapezoids, etc. Finally, mass or spaces (volumes) of like species may be compared and their proportions similarly derived.

When this comparison is made quantitatively, according to some mensuration, the resultant proportion is expressed as a mathematical ratio. For example, in segmenting into two parts a straight line 13 units long, the first part being 8 units long and the second 5 units, the ratio expressed would be 8/5. This fraction, then, may be expressed as a numerical equivalent. In this example it is 1.6. The equivalent is termed the proportionate mean. Thus the proportion of these two segments is 1.6:1. Similarly, with areas and space volumes, the comparative ratios of these may be determined, and their proportionate means will establish if, through their equality, they are in like proportion; and if disproportionate, what their particular proportions are.

When exact mathematical ratios are used to develop or express proportion for line, area, and space (mass), the representation is called geometrical proportion. The exact mensuration for the quantity comparison of geometrics is an objective or mathematical approach to proportion. It is the expression of exactly what is--independent of man, of perception, of variations in taste, of position and placement, and of all the variables in sensibility.

It is extremely important to attest that there is a second and perhaps more meaningful aspect of proportion as related to form. It is visual proportion and is subjective--dependent on man and influenced by perception through the sense of sight. Visual proportion as opposed to geometrical proportion is a qualitative comparison of the nature of form (line, area, and space) from the visual response to a particular set of circumstances. For example, the line in Figure 13 is divided geometrically into two equal segments. Because one-half is further partitioned, the original line does not appear to be equally subdivided. To insure, therefore, that the line appears to be segmented in the proportion of 1:1, the unpartitioned section actually must be made longer than the partitioned one. Similarly, the other examples shown in Figure 13 demonstrate that the eye cannot perceive mathematical ratios as such, but as they appear under a given set of circumstances. They are evident merely as visual ratios. Thus, from the standpoint of beauty or aesthetic effect the problems involved in the creation and evolution of form and content in a design are in part those of mathematical ratios, but are principally those of visual proportion.

In the study of proportion the problems of dimensional control, product sizing, ranges of sizes, and the positioning of materials, are viewed as they relate to production since technological advancement places an ever-increasing emphasis on automation. By the ever-increasing use of machinery, as well as technical acumen, greater quantities of materials and new material assemblies are made. Presized, preshaped, and preassembled materials, as well as entire building elements, are the production courses undertaken in the name of economy.

This study emphasizes the fact that there are several factors and groups which influence and set the proportions of school buildings and materials. The architect

with design composition determines definite proportions which set the dimensional aspects of elements and material parts. The manufacturer at the production level determines the range of sizes according to specific material limitations, according to manufacturing methods, and according to preferential proportionate sizes. Thus, whether applied by the architect at the design phase or by the manufacturer at the production phase, a dimensional medium must incorporate proportional aspects to demonstrate compatibility from the viewpoint of both design and production. The employment of such a medium allows the designer freedom of proportionate composition and provides the manufacturer with the required frames of reference for production sizing and subassembly.

E. Planning

Introduction

This study is performed to determine if it is necessary and possible to build into the dimensional system a technique specifically related to architectural planning. If this can be done, an attribute will be supplied which has not yet been proposed. After initial investigations were performed concerning modulation, it became evident that this technique could be applied to the building space arrangement or planning stage. The mechanics of applying a dimensional system have evolved from this study. Although the discussion within this section is developed from the broad architectural approach, the mechanics of applying the system for building product design are similar. From the contractor's viewpoint also application to job site construction operations is similar.

This section presents the establishment of (1) principal reference planes, (2) the setting or positioning of building elements and (3) their relationships to each other, which set the stage for the modulation processes. The first step in the total modulation process is called space modulation. The purpose is to modulate the spatial design. This results in grid patterns which express the dimensional relations of the spaces. These patterns act as the reference media to which the building elements, material systems, and material components are modulated, correlated, and coordinated in subsequent steps of the system.

Early efforts favored the rigid modulation method and thereby provided the opportunity of selecting different coefficients for different areas of the building such as one wing versus another. However, later application studies emphasized the need for the use of different coefficients within a single area. Thus it was apparent that both modulation methods (rigid and combination) had to be acceptable to space modulation.

Principal Reference Planes

The planning phase of school building design required the architect to determine the variety of particular spaces and area required to satisfy the educational program.

During this phase the disposition of these spaces is set and areas and magnitudes for the specific functions are defined.

In the planning phase it is necessary to make such decisions as materials to be used, the type of structural framing and its tentative disposition, and the location and coverage of the building or buildings in relation to the site. These as well as the educational philosophy of the school influence the configuration of the plan. The "space unit," "cluster," "loft," "finger" and "campus" types are generic names of particular solutions to individual school building programs. Once the plan is established and the material specifications determined, the modulation processes begin.

Modulation of Plan

The plan is modulated to produce the initial reference grids. Space modulation requires that the designer appraise his building plan to determine its repetitive aspects, the recurrence of similar elements and spacings, the structural framing disposition and spacing, frequency of design motifs, and the like. The character of the plan then will provide the key to a choice of the particular coefficients for use in modulating such a plan. Certain areas of the plan may indicate a modular coefficient different from that suitable to others. Thus, it may be desirable to utilize more than one modulation coefficient. This is apparent when the function differs in particular areas or subareas, where the conditions supporting the choice of certain modulation coefficients in these areas no longer prevail, or where they are different from other areas. When these differences occur, the applicable coefficients of modulation are selected for each area even though they may be different from those expressing the modulation of other areas or subareas.

Where the coefficients of modulations are different and where one area is to be correlated with another, the resulting grid lines must mesh as illustrated in Figure 14.

Thus, by selection of appropriate coefficients of modulation for the particular areas of a plan and by the meshing of grid lines to form the compatible whole, a grid pattern relationship will be established. The resultant pattern is the initial reference grid to which the position of elements and materials are correlated or dimensioned.

Positioning of Structural Element

The element is a major consideration in the basic stages of planning the school plant. The type, materials, framing, spacing, etc., are items which are evaluated and determined with space allocations and element disposition. When the preliminary plan evolves, the type of structure and its tentative placement in reference to the space is set. Consequently, when the tentative plan is set, the tentative structure is set.

At this point of design, the structure may be considered as being in one of two categories. First, it may have an integral relationship to the wall elements and space disposition, and the spacing and forming of areas may be coincident with the placement of the structural elements. Here, where the structure and spatial disposition are dimensionally compatible, the grid patterns resulting from the space modulation might also serve as reference grids for the structure. The second condition is where the structure is not coincident with the space enclosing elements. The structure is in planes independent of the space or wall element planes. The resulting structural grid pattern, expressing the structural element modulation, must mesh with the spatial planning grids at some specific grid line. This particular line or lines are marked for reference, as illustrated in Figure 15. Other elements must be referenced to and correlated with principal grid lines in a similar manner.

Nonrectangular Patterns

Various grid forms resulting from space moduation are studied, including such nonrectangular forms as rhombic patterns. It is found that these can be converted to rectangular representations and that in most instances such a conversion will allow for easier interpretation. If a plan is conceived on special patterns, it is advisable to modulate the plan by resolving the patterns into a rectangular reference grid reflecting the modulation. Using 3, 4, and 5 as the basic coefficients of modulation and the foot as the index of scale, the plan is modulated in the same manner as heretofore described.

Relationships or Planer Concept

The modulation of the plan for a school building design requires the adoption of several principles or postulates. One is the concept that the various building elements which form the spaces are planer and are not considered as volumes or solids. These elements are represented by two planes separated by a distance which is the nominal thickness of the element. The separating dimension, which establishes the plan positioning with respect to other building elements, is the thickness of the element at the intersection of this building element with another.

In planning, the elements creating the various spaces, which are perpendicular to the plan or plan element, are defined by the two planes intersecting the plan and separated by a particular distance which is the thickness of the element. It is of no concern here that variance in thickness occurs elsewhere in the element except at its intersection with the plan. For example, a six-inch wall defining two spaces in plan is considered as two parallel planes perpendicular to the plan and positioned six inches apart provided this is the thickness dimension at the plan level.

Tolerance

Another important consideration is dimensional tolerance. As applied to planning modulation, the nominal element thicknesses are held to integer increments of one

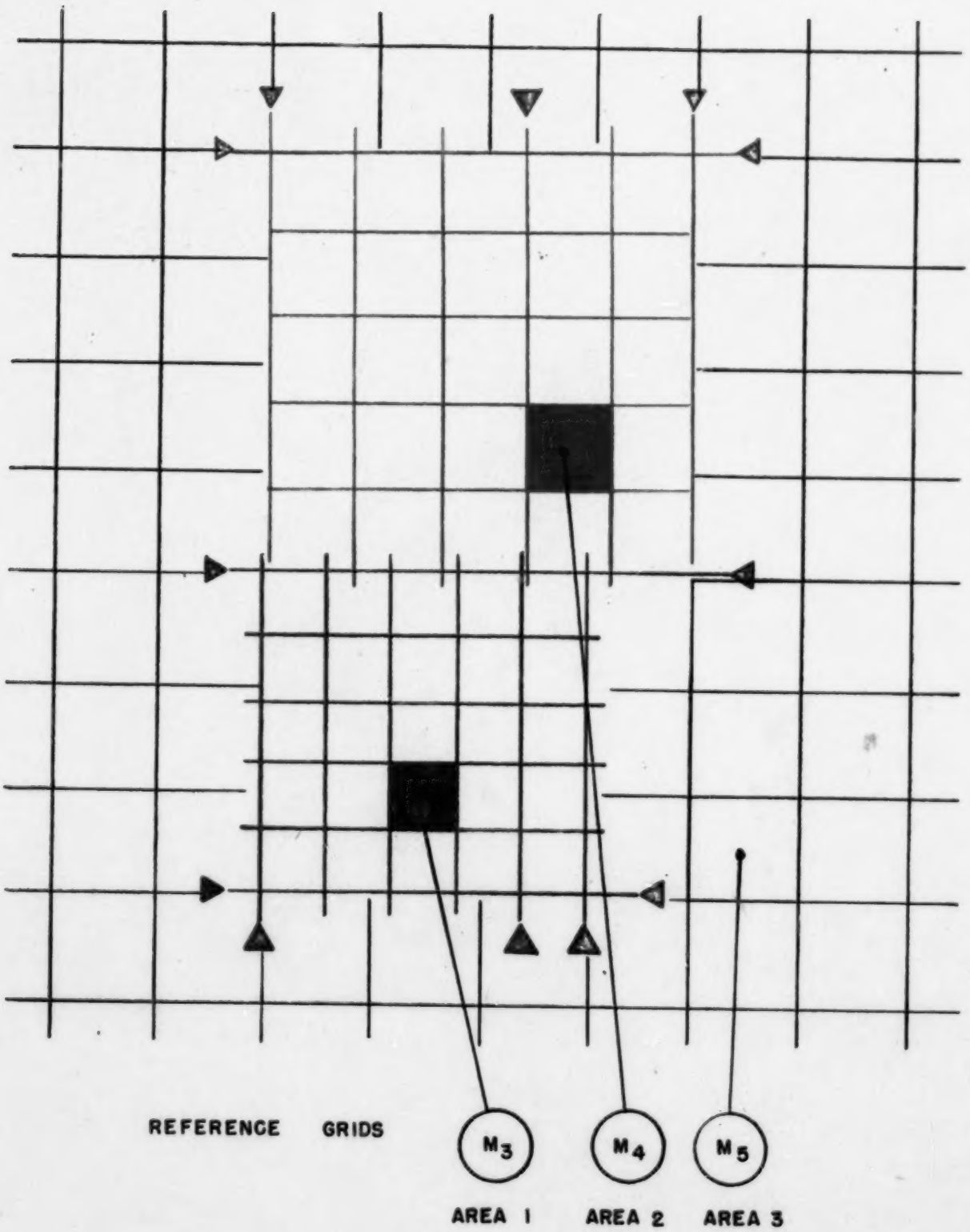
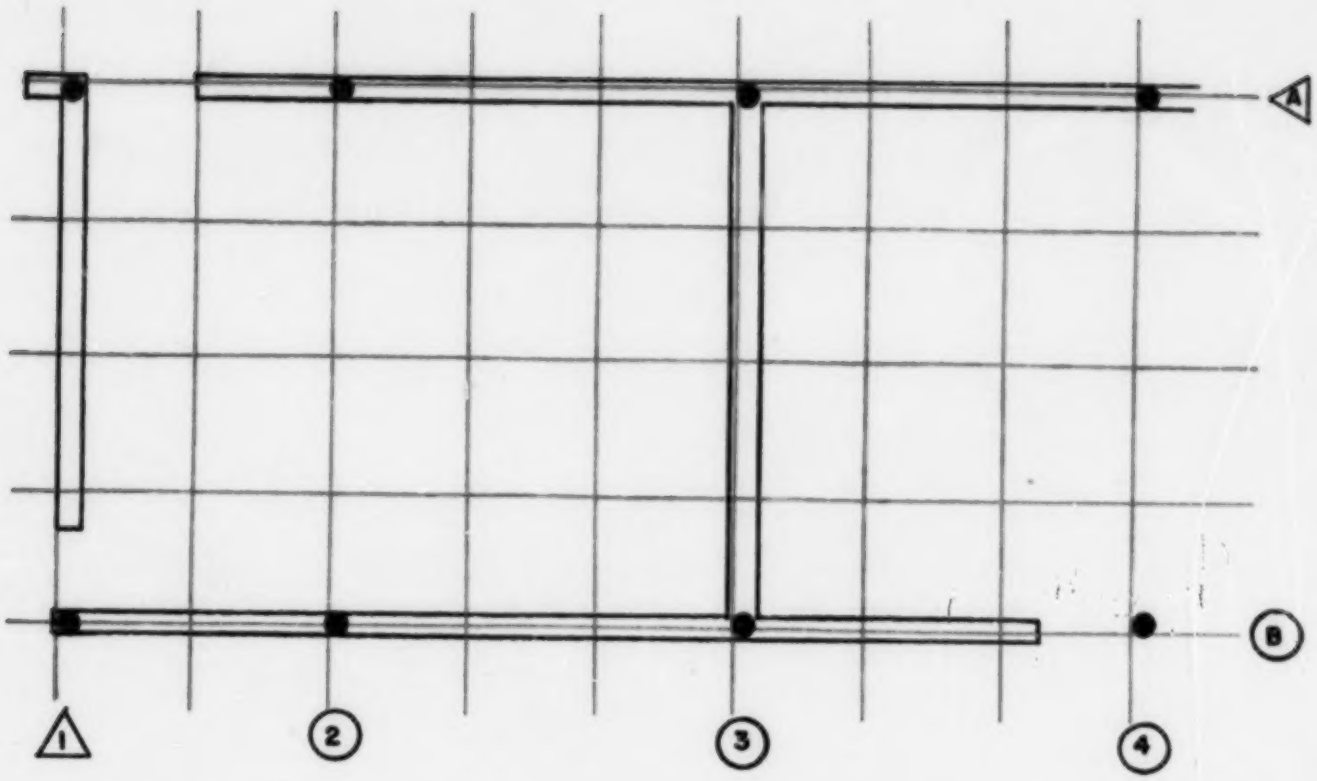
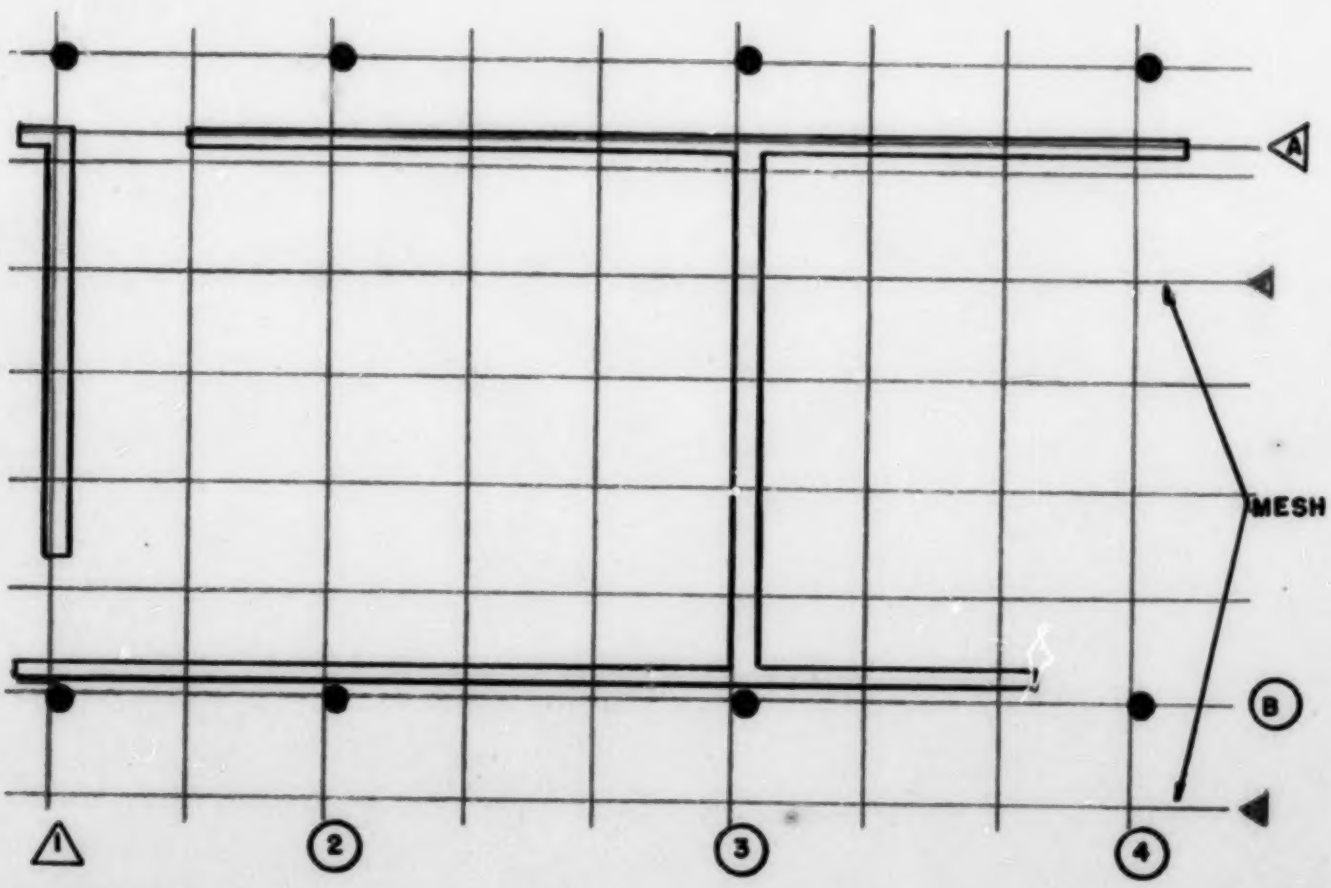


FIGURE 14 MODULATION OF THE PLAN



CONDITION 1: PLANNING AND STRUCTURAL GRIDS COINCIDENT



CONDITION 2:

SEPERATE MODULATION FOR STRUCTURES

FIGURE 15 SPACE MODULATION

inch. Thus, a nominal four-inch cinder block wall, plastered on both sides, is dimensioned as a five-inch wall even though its actual dimension is not 5 inches. In planning, all thicknesses are shown in one-inch increments.

Similarly, the placement of the elements in plan likewise requires a certain planning tolerance. This variance depends upon the placement of elements which define or limit the length of other intersecting elements. Thus, the positioning of one element plane parallel to another must be dimensioned nominally in increments which are compatible with the system and which allow the various tolerances necessary for the inclusion of other elements.

All elements, therefore, can be dimensioned from either or both of the two planes defining the element to either a modulation grid line or to the plane of the next element. These latter dimensions, from element plane to element plane, must be expressed as integers, not fractions. Since it is small, the actual difference in size can be resolved by the coordination detail.

F. Building Elements

Building elements are designed assemblages of building materials and/or component units. When combined, they form the building envelope. Specifically, the elements are those of the structure, floor, exterior wall, ceiling, roof, partition and services. Once their position is tentatively set in plan and the material or material systems of which they are to consist have been selected, their modulation is accomplished. The grid patterns resulting from modulation are used to represent the element and its subelements. These are then correlated to insure assembly within the element. The modulation and correlation steps create a dimensional order between the construction and the designed spaces preparatory to the final segment of the system. This means the accomplishment of the specific design detail which will provide coordination between intersecting elements.

Purpose

After the initial planning stage of design has been developed, the next major step to modular coordination of the building includes the modulation of building elements and subelements, correlation of components or assemblies, and the coordination of elements with other elements. The development of this second major step is the subject of this study.

Modulation Elements

Modulation of the element and its subelements is accomplished after the establishment of element and subelement limits. The limits are affected not only by the edge conditions or extent of the element or subelement but also their relation to adjacent or intersecting elements or subelements. Except in the case of simple elements, two or more modulations are required depending upon design requirements and ele-

ment complexity. Over-all building element modulation considers aesthetics, scale, proportion, etc., while modulation of the subelements concerns the material families which comprise the element.

Modulation is carried out according to the methods described above. The selection of the appropriate method is determined by the particular conditions which apply to the specific element or subelement to be modulated. The index of scale chosen for modulation depends upon the design, the details and the construction systems comprising the element. The composed grids resulting from the modulation as influenced by function, aesthetics, construction materials and systems, become the dimensional reference for detailing, materials fabrication and site assembly.

Correlation of Components

When the various building elements have been modulated, the resultant grid patterns must be correlated. The grid arrangements are positioned so that they make a reference pattern which is an orderly, compatible and dimensionally linked complex.

The subelement modulation grids are combined with and correlated to the main element grid pattern as shown in Figure 16. This is performed in two steps. First, the subelement grids must mesh or be correlated by dimension to the grid pattern of the parallel reference plane of the main element. Where particular grid lines of one plane are coincident with the grid lines of another, the grids mesh and a reference datum common to both grid patterns is formed. Where there are more than two patterns representing more than two subelement planes, they must mesh at some particular grid line common to all and in addition to the element grid.

The second step is to correlate the subelement planes within the thickness of the principal element and normal to it, or in the third direction. In Figure 17, these planes are correlated by dimensions to either of the nominal surface planes representing the element. The sum of the correlation dimensions (thicknesses) will then equal the element thickness.

The elements are dimensionally related in plan to the reference grid pattern resulting from the process of space modulation. In elevation, the element planes which are parallel to the plan must also be related to the main reference systems. This is accomplished by dimensioning the nominal element surface planes to the vertical reference grids produced by space modulation. All reference grid patterns resulting from the modulation of the building space and the building elements thus are correlated dimensionally.

Coordination of Material Elements

To this point, the plan, the building elements, and the subelements have been modulated. The representative element and subelement planes and their resultant reference grid patterns have been correlated. The remaining step necessary to com-

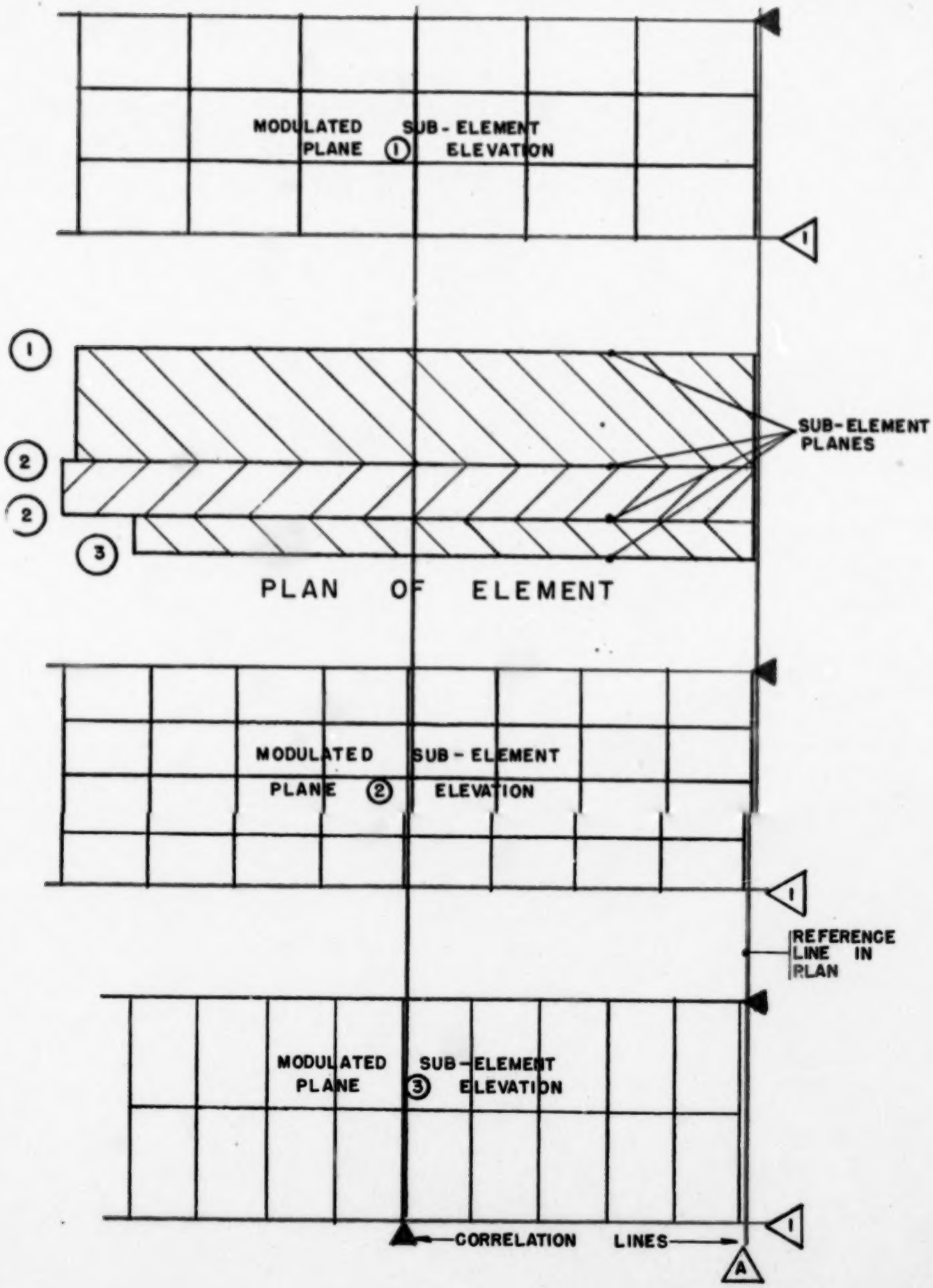


FIGURE 16 CORRELATION OF SUB-ELEMENT PLANES

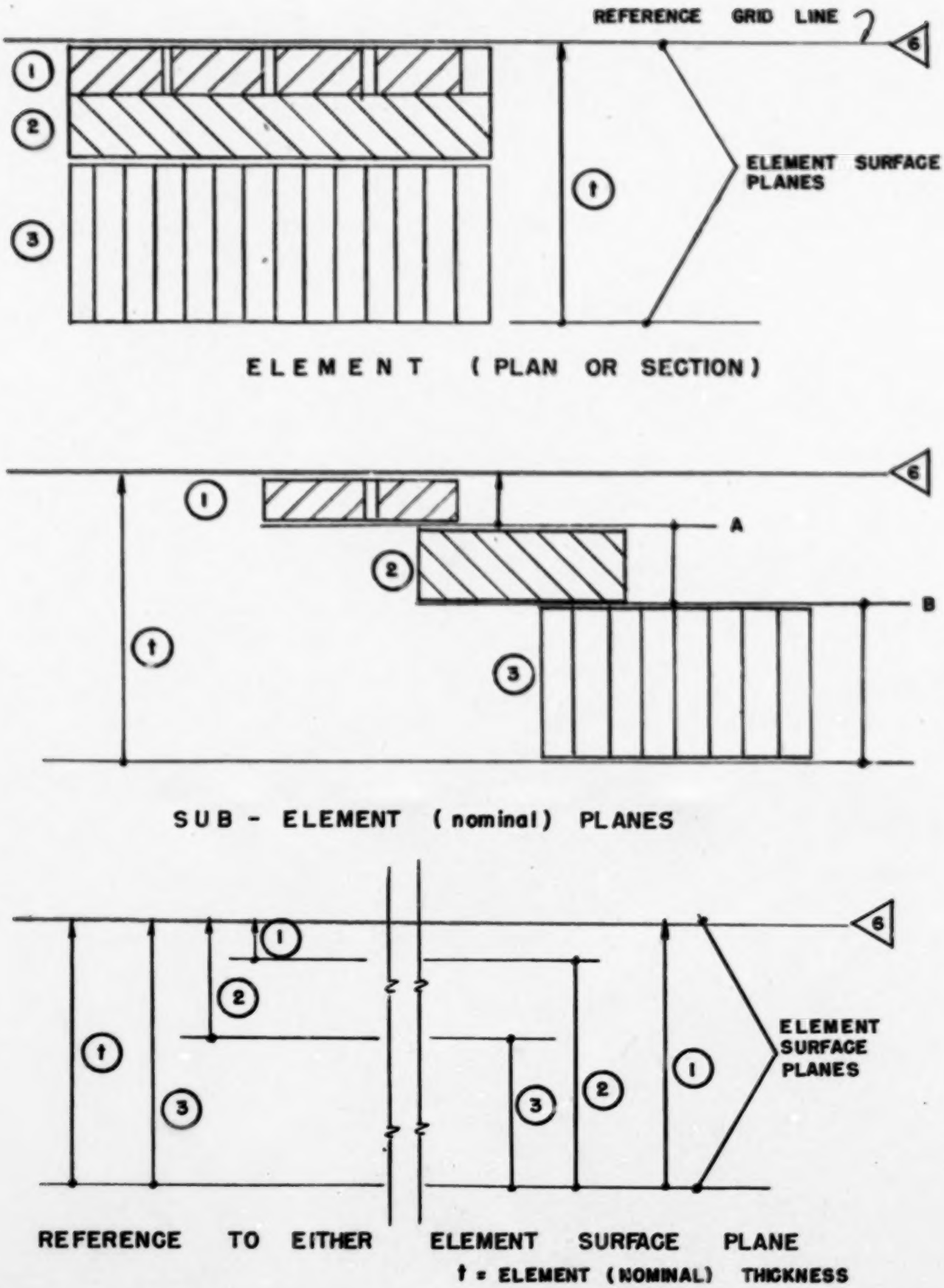


FIGURE 17 CORRELATION OF SUB-ELEMENT PLANES

plete dimensional integration in accordance with the reference system is that of coordinating building elements to building elements.

Coordination is achieved by determining the appropriate detail which relates the material assemblages at the various element intersections. This should be accomplished in a manner so that no major modification of the moduation or correlation steps will be necessary. There are numerous influencing items which must be considered: the element and its functions, requirements, the complexity of element composition, the variety of intersections, the basic juncture conditions, the number of different materials and their relative positioning.

Since the elements and subelements are represented by planes, the problem of coordination is resolved when the dimensional relationship of these planes is determined. This resolution is represented graphically by construction details of the intersection of these planes.

Each designer develops the series which satisfies the criteria of his problem. Two typical element intersections are illustrated. The first, Figure 18 shows the juncture of the floor and exterior wall elements. In vertical section, each with its subelements is represented by the nominal surface planes. The grids resulting from modulation are indicated. Coincident or meshing grid lines are accented by the small solid triangles to indicate correlation at either the inch or foot scale grids.

The second illustration, Figure 19, is the intersection of an exterior wall element with the roof-ceiling element. Here again, in vertical section, only the surface planes representing the parameters of the elements and subelements are shown.

In these illustrations, materials or material systems are purposely omitted since the examples depict merely the reference system or framework which assists in the over-all planning, detailing and assembly. Materials, however, are included in the studies exemplified by these illustrations. Several systems of existing materials may be selected which will fit directly into the framework shown. This dimensional reference, therefore, provides the frame onto or into which materials, components or material systems may be placed or fitted.

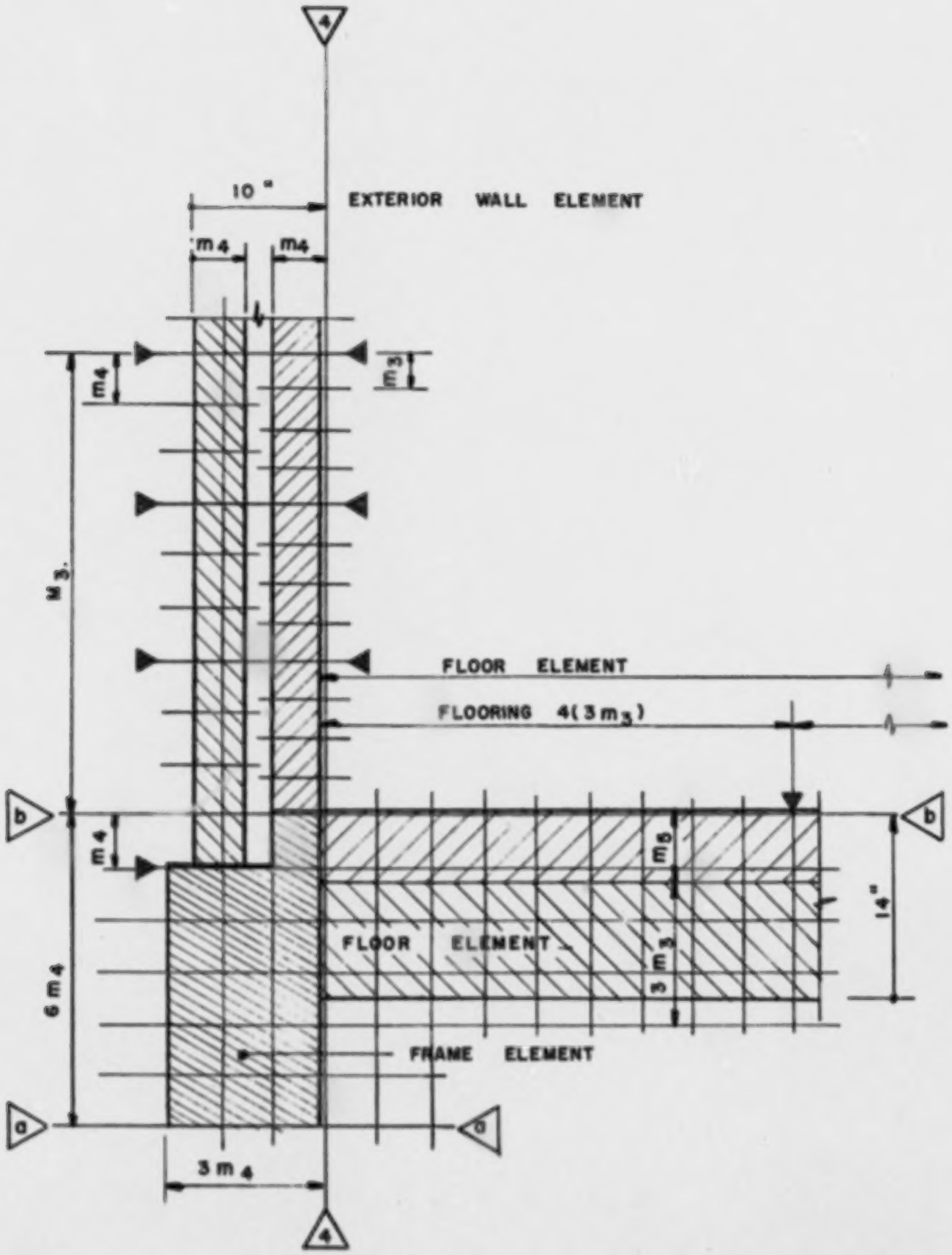


FIGURE 18 ELEMENT COORDINATION DETAIL

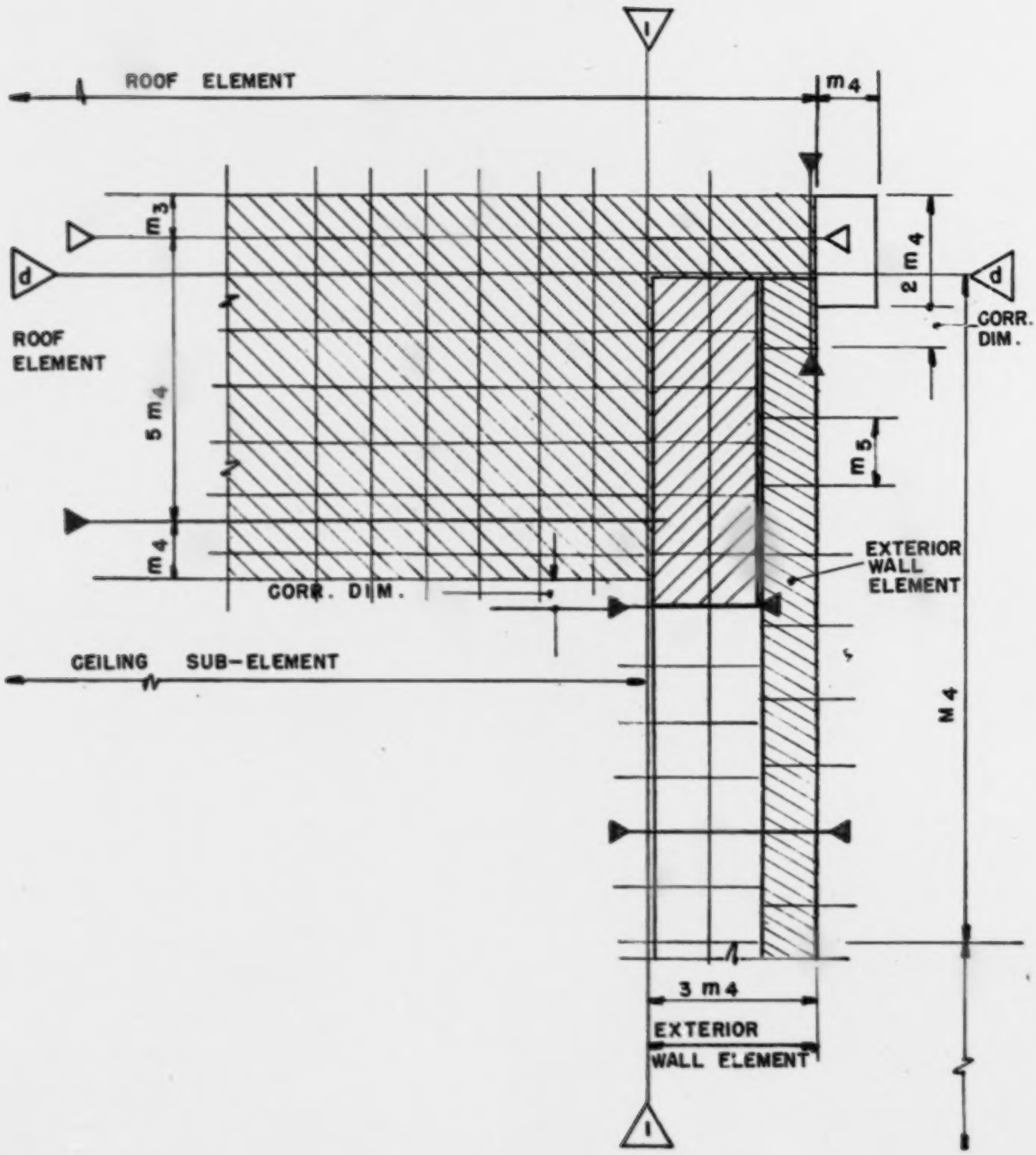


FIGURE 19 ELEMENT COORDINATION DETAIL

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4. THE SYSTEM

A. Introduction

The developed dimensional system is a method which may be employed during the process of creating a building in order to achieve dimensional order for the purposes of modular coordination. This section describes the system, its significance and how it is used.

The system was developed as a method of dimensional reference with which the sizes of areas and spaces resulting from school building design, as well as the size of material products to be placed by construction, can be related and coordinated within modular concepts. This involves the unification of dimensions of building spaces with the stock building products. The system makes construction coordination more efficient. It does not, however, preclude that such high efficiency is attained unconditionally throughout all areas of application. Some building products and/or construction systems can be only as dimensionally efficient as they are sized within their own material system. In cases where these material systems are utilized, the importance of the system for design and construction is that of relating several material systems. Thus, the various processes required for modular coordination as applied to the entire building complex are of utmost importance.

B. Description

The system is best described as a method of achieving dimensional order. It is used when coordinating dimensions for building spaces, building elements and materials and is an aid to the coordination of building construction details. The system consists of (1) primary segments, and (2) supporting tools and aids. The segments are the establishment of the frame of reference by identification of principal planes of reference, modulation, correlation, and coordination. These are stated in their relative order of sequence use within the system's total application. The supporting tools and aids are modulation methods, number pattern, number combination tables, grid patterns, and symbolic representations. The supporting tools and aids may be applied within any of the segments and have no particular relation to sequence in the application of the dimensional system.

In developing a complete system, it was recognized early that consideration must be given to the various tasks involved in the total process of design and construction. In addition, the system must be not only in line with procedures, skills and responsibilities of the involved professions and trades, but also must provide sufficient flexibility to cope with numerous variables associated with building design and construction. As a result, the system will take different forms of application depending upon the particular use by the architect, engineer, material producer-fabricator, and construction contractor.

System Segments

The system segments constitute the establishment of the planes of reference, modulation, correlation and coordination. The planes of reference constituting the frame are established as a key to the total design and construction. The principal reference planes facilitate the organization of the parameters and the relative positioning of the primary building spaces, elements and subelements. These planes should be positioned at significant junctions of building spaces, units and/or construction systems. They will form the frame of reference when modularly linked to each other. The frame acts as a base for all control dimensions.

Modulation is accomplished lineally in two directions. The resulting expression of modulation forms specific grid patterns, which comprise the lines indicating the locations of elements, material systems and components, as well as the various positions for correlation purposes. The grid patterns act as subreference planes for dimensioning purposes and are companionable with the main reference frame.

Correlation is accomplished during the process of modulation by relating corresponding grid patterns so that the particular grid lines will coincide. This condition has been termed meshing of the grid lines.

The coordination segment may be described as that part of the process where final organization of the construction is achieved dimensionally within the patterns and planes of elements and at the juncture of material elements. It is here that the coordination relationships are made final by setting the detail dimensionally between different construction systems and/or material products so that assembly can be accomplished readily. The actual construction detail is not determined by the system; this is accomplished by the designer. The coordination detail is part of design; thus, there are a variety of possible solutions. Although solutions must never be standardized to the extent that static, sterile design and construction will result, the system must incorporate coordination insofar as setting up the dimensional relationships of construction so that the details can be accomplished with dimensional assurance.

System Tools and Aids

The tools and aids of the system are modulation methods, number patterns, number combination tables, grid patterns and symbolic representations. Modulation is a segment of the system but it can be accomplished in several ways. The means of modulation must have been resolved by two methods, which thereby become a tool of the system.

Modulation Methods. The first method is termed Rigid Modulation. The numerical expression is a repeating series or sequence, the constant difference being selected linear module. The graphic expression is a regular grid pattern whose grid line spacing has a fixed order of magnitude in either direction based on the selected

module for each direction. Thus, a repeated square or rectangular grid is the result.

The second method is called Combination Modulation. Here the numerical expression is achieved by the use of two or more selected modules in one or both directions. The series or sequence that results from the use of this method is not regular or repetitive; rather, it expresses the determined relation and position of different size units and/or magnitudes for the particular design and construction under study. The graphic expression is a grid pattern where grid line spacing is not regular or repetitive. The spacings reflect the determined combination or units set in harmony with the particular design.

The number pattern. The number pattern is the general numerical reference which expresses the relation of numbers based on the coefficients 3, 4, and 5. During the application of the segments of the system, certain controlling numbers, specifically appropriate for the particular building design under study, will be apparent. Since these numbers must be related, reference is made to the number pattern for the appropriate relation which will satisfy the conditions of the design problem. By reference to the pattern, appropriate number combinations are selected for the specific design and are then incorporated within the controlling numbers in order to process the requirements of the particular segment. As the numbers increase in value and/or quantity, and as the complexity of the design and/or coordination becomes more involved, additional numerical solutions are possible. Discovery of the numerical solution requires a more definitive reference than can be readily supplied by the number pattern. Thus, an auxiliary and companion tool is provided, i.e., the number combination tables.

Number combination tables disclose the combinations to achieve a particular number based upon the selected basic coefficients. The combinations which satisfy a particular situation are then examined to determine the final appropriate selections. These numerical combinations are employed to set the related units of design and/or construction and are expressed by their respective grid patterns.

Grid patterns, also aids within the developed system, act as a means of graphically expressing the dimensional relation which results from the application of the segments and tools of the system. The grids are scaled representations of the final solution. When particular grids are determined, they serve as controls or a means of control to which other necessary grids are related. Thus, the total dimensional relation is keyed and controlled by a network of grids expressing the total dimensional order for the particular design.

The final tool of the developed system is symbolic representation of reference planes and dimensions. The positions of the reference planes are identified by lines which are terminated with bold triangles. Within each triangle a letter or number is placed to identify the particular reference plane. Vertical planes in one direction are designated by an upper case letter. Arabic numbers are used to designate the perpendicular direction. Lower case letters are used to identify horizontal reference planes. At particular locations in detail (large scale) drawings, the

symbols are repeated to key the detail to respective plans, elevations or sections. Dimension lines are terminated with specific symbols. Where dimensions terminate on grid lines, arrowheads are used. Dots are symbolic where dimensions do not terminate on a grid line.

C. Significance Of The System

The significance of the system is that by common means it unites the major facets controlling the dimensional relationship of buildings and their construction segments. The inherent versatility of the system, which may be exercised by the architect, engineer, material producer-fabricator and construction contractor for individual and combined purposes and problems, is in itself a significant fact.

Acceptance or the degree of significant acceptance is, of course, relative to the degree of application or system employment. For example, there are certain specific requirements for dimensional control that are inherent in design. It is here that the designer may exercise his prerogative. In some instances only that degree of dimensional control generally practiced today is desired. On the other hand, dimensional control may be increased to the extent of including electrical and mechanical solutions. This control, if not exercised by the architect or the mechanical designer, is left to the particular construction contractor or his tradesmen. Employment of the system by the contractors would permit them to assemble additional components or subassemblies in the shop under controlled conditions, thereby reducing site labor and time, and this would encourage competitive construction.

The resulting impact of the system in useful application will be conditioned by overall understanding and acceptance. Although it will take time to substantiate, the end results will indicate the system can increase total dimensional efficiency so that increased savings and/or better quality will result.

D. How The System Is Used

The system is used by the architect and engineer, the material producer-fabricator and the contractor and construction personnel as illustrated by the following examples.

Architect and engineer. As employed by the architect and engineer, the system is used to reference and relate dimensionally building spaces, building elements and materials and to help in the coordination of building construction details. The first step of the system is the establishment of the principal planes of reference which are combined to form the reference frame. This frame serves as the datum or skeleton for the total dimensional process involved in planning, design and the production of construction drawings.

Modulation is the act of relating in an orderly fashion the several parts of the entire building complex, and the positioning within elements and referencing of the parts to specific planes. The sequence of modulation is initiated with the largest elements, which necessarily affect the relation of the smaller elements.

As the process continues, it becomes necessary to correlate dimensional elements to elements, material systems to material systems, and component product units to component product units, as well as to the material systems and elements containing them. Correlation means relating unlike dimensions and increments of assemblies to coincident reference lines as required by particular designs. It is expressed by the meshing of lines on the grid patterns which as stated previously, are considered tools or aids. Correlation will be discussed later in more detail.

The final segment of the system is coordination. Up to this point, the total construction has been related dimensionally by the use of a modular linkage medium. Coordination, however, concerns the detail junction of the building material parts and elements one to the other. In most cases several solutions will be applicable; thus, freedom is allowed for design and effect and for choice of placement. The system helps to relate the construction in an orderly fashion so that coordination may be accomplished.

Producer-fabricator. The material producer-fabricator is concerned with the efficient use of bulk stock, production of stock component parts, and subassemblies. He is concerned further with the sizing of particular products so that they may be used efficiently with those of other manufacturers.

The scope of the system is broad, and, therefore, its application will vary according to the particular building material products. Some producer-fabricators may be concerned only with the tools and aids. Others that produce material systems will also employ primary segments. It is difficult, therefore, to set a uniform sequence of and applicability of the system parts that will serve equally all building product manufacturers. The concern, which is of paramount importance to this project effort and common to all products, is that the products, whether parts, components, or subassemblies must necessarily be sized during manufacture. The problem was the development of a method by which sizing can be accomplished that will satisfy the greatest possible demand without shop or job-site resizing. The tools of the system which may be applied to help determine the most appropriate sizes are the number pattern, combination tables, modulation methods and grid patterns. The system segments which may be applicable are modulation, correlation and coordination.

Contractor. The principal advantage of the system to the contractor and construction personnel will be the use of the primary segments. The sequence of application will be similar to that used by the architect. The process, however, is reduced to the extent of establishing or verifying dimensional aspects in accordance with design. The frame and its planes of reference are identified and established

at the site as required by the contract drawings. The remaining segments, e.g., modulation, correlation and coordination, are to be accomplished in order as set by the design. Construction contractors may apply the system to achieve efficiency in completing related work. For example, all falsework such as shoring and forming could be laid out and erected in accordance with the aid of the developed segments and tools. Other dimensional relationships, not controlled by design, could become orderly by application of the system.

5. DETERMINATION AND APPLICATION OF THE ESSENTIAL COMPONENT PARTS OF THE SYSTEM

A. Introduction

The determination of the essential component parts of the dimensional system is achieved by studies of various examples of application which concern building designs, elements and material systems. The studies result in two specific examples illustrated in this section which show the method and procedural steps involved in applying the system to actual school buildings already constructed and in use.

The first school example, which is a less complex illustration, indicates the use of the system. In certain instances, drawings are used to indicate the significance and/or over-all resultant use from a particular operation or segment application.

The second example is a more complex design. The system application in this instance is shown and described in a manner and sequence which represents the particular use of the various segments and tools and aids of the system. The illustrations, therefore, show selected drawings closely resembling those produced by various school designers resulting from system application.

B. Example Of Application

Example Number One: The six-classroom addition to the Nesconsett School designed by Ketchum, Gina and Sharp, Architects.

Design

In this school the educational program required space for 162 elementary pupils which, in addition to classrooms, included adequate indoor activity area, toilet rooms, storage areas and equipment. The disposition of the plan was resolved into six classrooms arranged in a symmetrical layout around a connecting central activity-access area. This one-story school addition was a detached building located on a level site close to an existing school plant.

The structure had a steel roof deck spanning the classroom width and supported by load bearing brick walls. The floor was constructed of a reinforced concrete slab-on-ground terminating at the building periphery where concrete foundation walls extended below grade to continuous spread concrete footings. The fenestration was accomplished by the use of window walls extending from slab to roof construction. All services were brought to the building underground through pipe trenches beneath the floor slab.

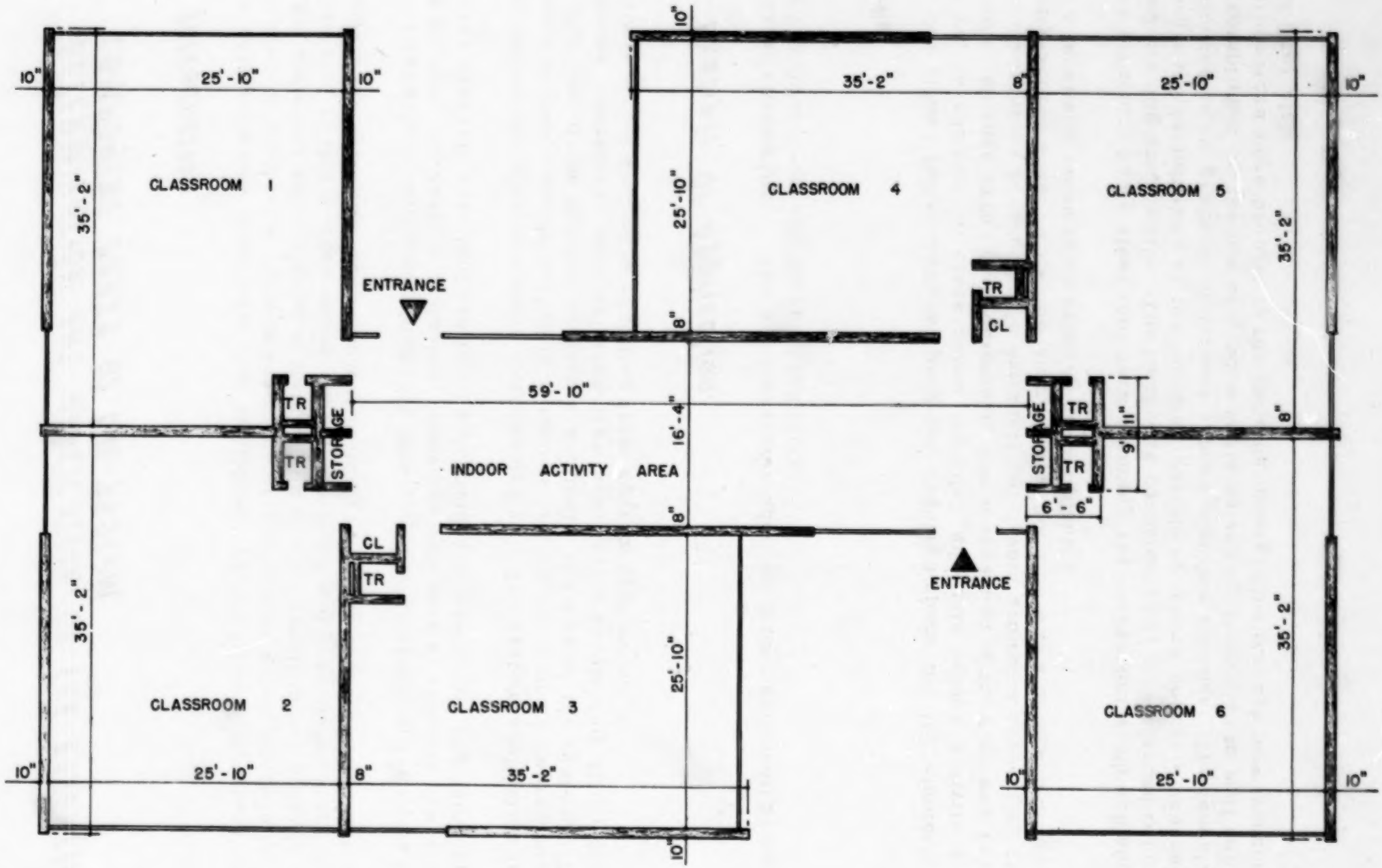

FIGURE NO. 20 PLAN: SIX CLASSROOM ADDITION

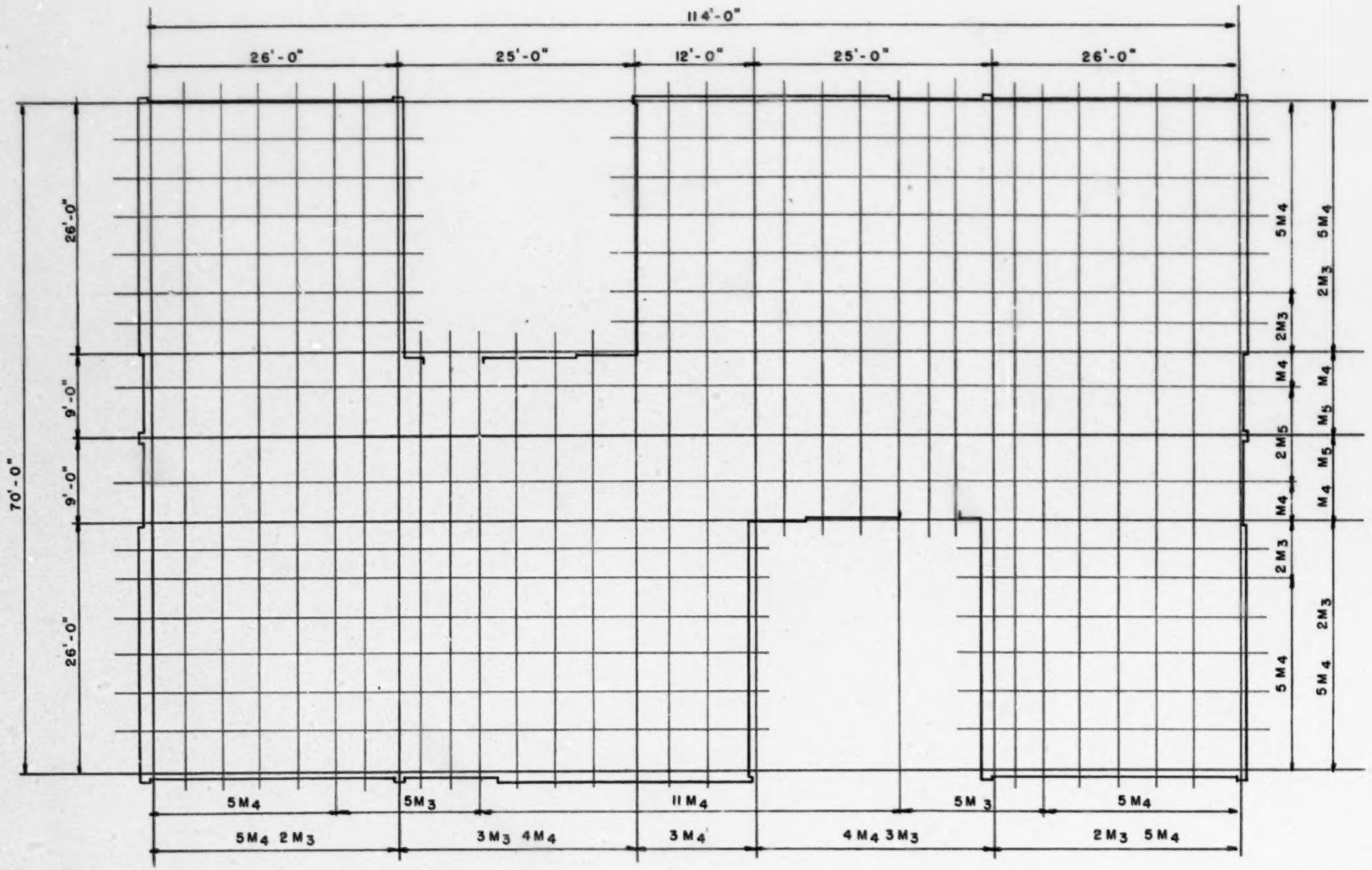

FIGURE 21 MODULATION OF PLAN

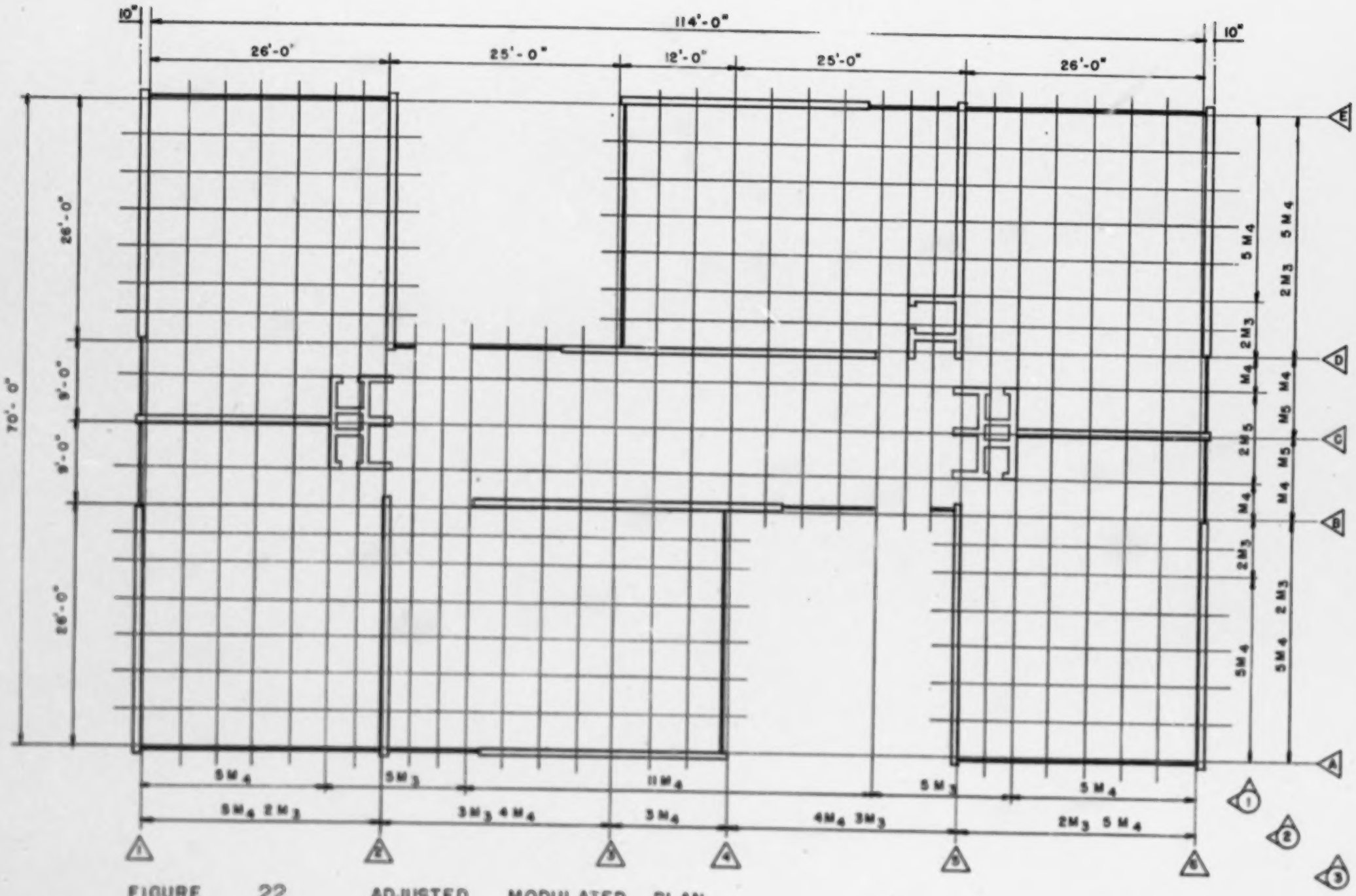

FIGURE 22 ADJUSTED MODULATED PLAN

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The principal materials used in the building construction were:

Reinforced concrete for floor slab and foundation,
Asphalt and ceramic tile for floor covering,
Brick and concrete block exposed for load bearing walls,
Steel window wall for fenestration, and
Clearspan exposed steel deck with rigid insulation and built-up roofing for roof construction.

Space Modulation

The initial step in the modular coordination effort is taken when the design is set by the staff, and the preliminary plans and elevations, including perspectives and lists of materials, are approved by the school authorities. The plan is shown in Figure 20. This step requires the over-all modulation of the school building design. The purpose of space modulation is to establish the principal planes of reference which will appear on all subsequent drawings as lines to which elements and materials are dimensioned or referenced. These planes, when grouped, form the primary frame of reference.

In modulating the plan, the space configuration, the composition and disposition of the material elements, and the structure are important influences which aid in determining the specific modulation sequence. When a definite sequence is established, it is represented on the plan by lines of certain modular-grid spacings, and in this case, on the foot index basis. The sequence of reference lines is expressed in large M. Thus, for instance, as shown in Figure 21, the modulation of the widths for classrooms number 1, 2, 5 and 6 is $5M_4$ $2M_3$. The selection is conditioned by the toilet and storage area requirements. Similarly, the modulation of the width of classrooms number 3 and 4 is influenced by the toilet-storage space and is the same even though its modulation direction is normal, like unto the other four classrooms. Similarly, the lengths of classrooms are modulated. The space modulation in one direction, therefore, is resolved as follows: $5M_4$ $5M_3$ $11M_4$ $5M_3$ $5M_4$ and in the normal direction: $5M_4$ $2M_3$ M_4 $2M_5$ M_4 $2M_3$ $5M_4$

From this spacing, the principal reference grid lines are determined in both directions. At the same time the slight adjustments can be made to position wall elements so that they are placed for optimum element material coordination indicative of the particular dimensional ranges of materials required. Figure 22 shows the adjusted plan with the modulation grid as well as the principal reference frame pattern. The reference lines are shown in red and are identified as 1 through 6 in one direction and as A through E in the normal direction. All elements and material systems are dimensioned or related to these reference lines. The architect references all design dimensions to these lines, the contractor uses these lines as the construction datum and the manufacturer may index to them in the fabrication and the subassembly processes utilizing stock products.

Thus the space modulation of the plan requires three steps--as shown in Figure 22--over-all modulation of the plan on the foot index basis; adjustment of the plan elements; and selection of the principal reference lines from the modulation grid. Although these steps are accomplished by the architect or designer, they affect each succeeding step in the total process and are, therefore, of interest to the producer and contractor.

The vertical space modulation is influenced by several factors. The space disposition, the principal element material systems, the exterior and interior elevations, the major component dimensional characteristics (such as doors, sills, structural members) are all pertinent considerations. The influence and importance of these items upon the modulation is weighed and evaluated. The vertical modulation is then carried out, and in this case, on the inch-scale index. The sequence of referance lines as determined is expressed in small m, as in this example m_4.

The vertical modulation for this application resolves into a constant sequence of m_4. Total modulation for this design solution is $42m_4$. With the over-all modulation set, the principal reference frame must be selected and indicated. Figure 23 shows the four major reference lines in red and identified by lower case letters ◁a through ◁d . These give a spacing of $12m_4$ $20m_4$ $10m_4$ between principal reference lines. By setting the vertical reference lines, the school design now is resolved into a three dimensional reference frame to which all items are dimensioned and finally placed. This makes the modular skeleton of the building.

Element Modulation

Elements are the main building units, such as structure, walls, partitions, floors, ceilings and roof which define the building spaces. Depending upon the design criteria for a particular building, certain elements may or may not be included. In the design for Example One, a separate ceiling element was omitted since the underside of the structural roof element was detailed to act as the ceiling.

At some time during the modular process, each element is modulated so that it may be dimensionally organized within itself and be dimensionally related to the other elements comprising the building. In the interest of conciseness for this presentation, only the exterior wall and structural roof elements are treated. If the other elements had been included, each would have been handled similarly, thereby achieving dimensional orderliness.

Exterior Wall Element modulation including fenestration is explained. Figure 23, for example, shows the modulation of the south elevation of the exterior wall of Classrooms Number 2 and 3. For Classroom Number 2, the entire element area is window wall. This is separated from Classroom Number 3 by a projecting 8" brick wall element. Classroom Number 3 includes both a window wall and a solid brick area. The window wall for both classrooms follows a design which utilizes varying sized repetitive units. The proportions of these units, the divisions created

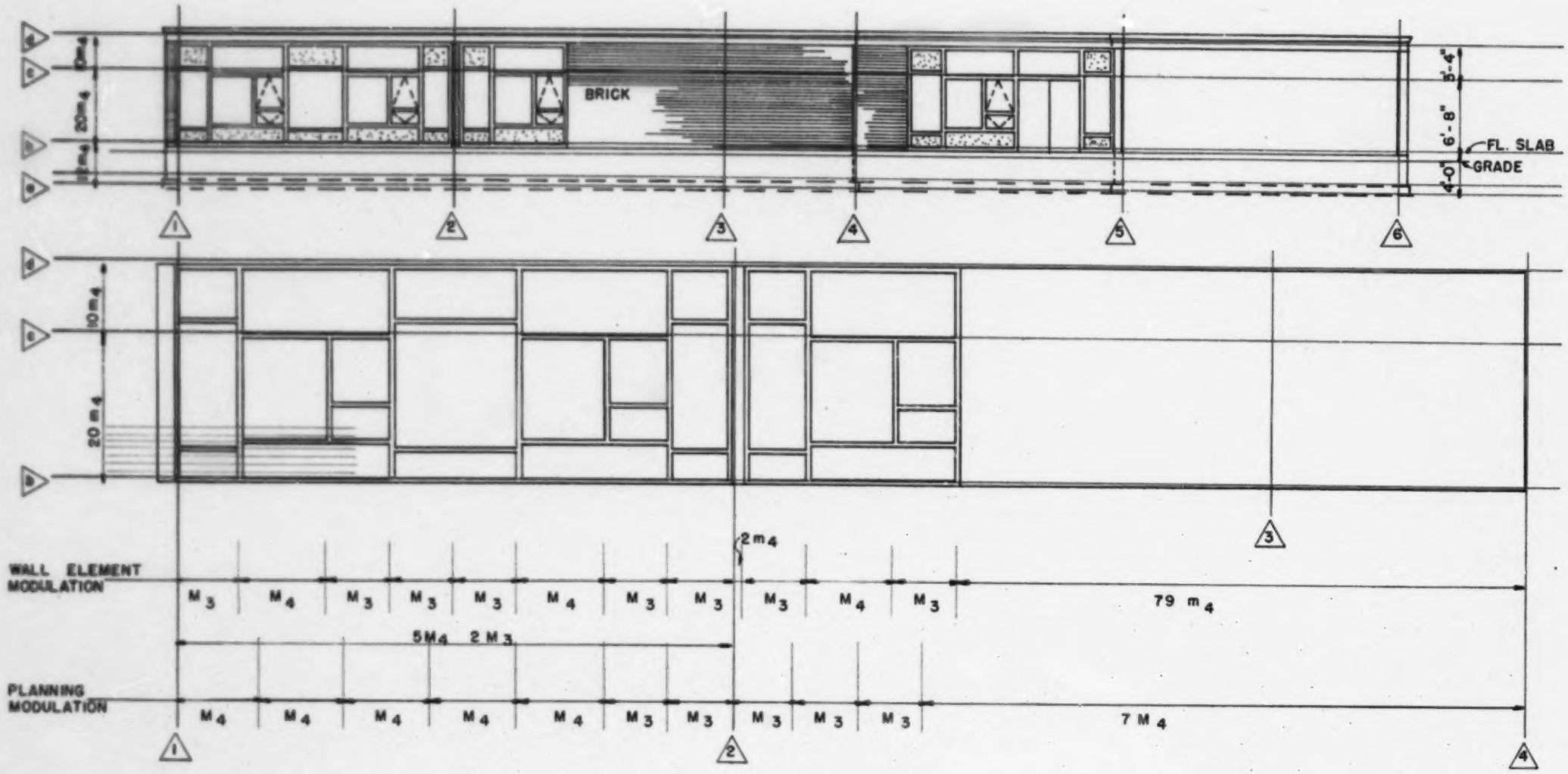


FIGURE 23 EXTERIOR WALL MODULATION

by the 8" partition wall, and the dimensional aspects of the brick wall material all influence the horizontal modulation of this wall element. The element is modulated as: M_3 M_4 $3M_3$ M_4 $2M_3$ $2m_4$ M_3 M_4 M_3 $79m_4$ or 63'-0" while the space modulation in the parallel direction between reference lines 1 and 4 is: $5M_4$ 5M3 $7M_4$ or 63'-0".

The two modulation sequences mesh at principal reference lines 1, 2, and 4 shown in red. Since the window wall is controlled dimensionally by the projecting brick walls of Classroom Number 2, the element modulation must mesh with the space modulation at these points. The window wall in Classroom Number 3, however, is treated as a subelement within a brick wall, much the same as a door in a partition. Thus, the material pattern is brick-window-brick. Here the window is a partial repetition of that for Classroom Number 2 and therefore utilizes similar modulation of M_3 M_4 M_3. This is the dominant rhythm of the fenestration. The modulation of the brick areas on either side of the window is compatible with the dimensional relationships of this material assembly, or m_4. Thus, the brick areas are $2m_4$ and $79m_4$, which with the fenestration produces the over-all modulation for Classroom 3 exterior wall element of: $2m_4$ M_3 M_4 M_3 $79m_4$.

The vertical modulation of the exterior wall element is the same as that for the building which is indicated in terms of small m and in this example is: $12m_4$ $20m_4$ $10m_4$.

All element modulation is carried out under the direction of the architect as the design of the plant is developed as modulation is allied more closely with design than with other segments of construction.

Structure

The architect in collaboration with the structural engineer determines the structural modulation and sets its reference grids. As indicated under space modulation, the structural framing was evaluated and its disposition was taken into consideration when selecting the sequence for both the horizontal and vertical space modulation. The type of structure in this example is such that it is compatible with the disposition of the elements resulting from the design. The structural modulation, therefore, coincides with the space modulation, and the principal reference lines selected are the same for both.

Utilizing these reference lines, the framing plan shown in Figure 24 relates the structural elements to these principal lines. Similarly, the foundation plan, Figure 25, shows the location of concrete foundation walls, footings and trenches, and relates dimensionally the positioning and sizes of these elements to the reference grids.

The vertical position of these elements is likewise referenced dimensionally to the principal vertical reference grid lines selected from the resultant vertical modulation during the space modulation operation. Figure 26 shows by sections the general vertical disposition of these structural elements in relation to the principal reference lines.

The structural subelements such as the steel roof deck may then be expressed dimensionally in terms of the principal reference frame or grid shown in red in Figure 27. Thus, the over-all size and variety of sizes of the roof deck components may be immediately taken off the drawing by the subcontractor and manufacturer-fabricator. For instance, shown in Figure 27, the lengths of roof deck components for locations, identified as (A), (B) and (C) on the plan, may be determined with a knowledge of the subcontractor's assembly tolerances, (t). In the case of (A), both end conditions are identical, shown as (33); for (B), the end assembly conditions are (33) and (31); and for (C), the assembly conditions are (21) and (1). The type of structural component member and its function, location, and dimensions sets the particular end assembly conditions which determine the over-all range of sizes of components for the structural roof element. In this instance the principal reference grid spacing between △1 and △2, and ◁A and ◁B is 26'-0". The end conditions for determining deck lengths are shown in Table VII.

The vertical location of the structural roof deck is referenced to the principal horizontal plane resulting from the vertical modulation process, and identified on all vertical sections and elevations as the red ◁d reference line in Figure 27. The horizontal structural angle components supporting the deck are set on this line which is $30m_4$ or 10'-0" above the principal reference (floor slab) plane, ◁b. The steel roof deck, therefore, rests on these structural components and is positioned 3/16" (thickness of the angle legs) above the plane of rest for these angles (the ◁d reference line).

The range of size for the basic width of this roof deck was established by the manufacturer at $3m_4$ and $6m_4$. For the (C) locations, the setting of M_4 $2M_5$ M_4 between principal reference lines ◁B and ◁D have been established by space modulation. Each edge condition as shown on the section detail in Figure 27 is less m_4 and t (the assembly tolerance) or 4" + 2" = 6". Since the range of size is $6m_4$ or 24", the total extent in the width direction is M_4 $2M_5$ M_4 less $3m_4$ or 18'-0" less 12" = 204". This will accommodate 8 units of the $6m_4$ size and 1 unit of the $3m_4$ size. This points out the role of the fabricator in establishing the particular range of dimensional sizes within the over-all unit dimensions so that coordination is possible and commensurate with other components or elements generally used in conjunction with this particular material system.

Material Systems

The exterior wall elements comprise two general material systems. One is the window wall or fenestration and the other is brick. These two material systems harmonize simply within a wall element. The element itself correlates dimensionally with the principal reference lines resulting from the space modulation. For example, Figure 23 shows the exterior wall elevation for Classroom 3 and the space modulation between △2 and △4 which is $3M_3$ $7M_4$ or 37'-0" and the element modulation of $2m_4$ M_3 M_4 M_3 $79m_4$ or 37'-0". From this latter modulation it is not difficult to identify where the subelement material systems are located. The $2m_4$ and $79m_4$ is the brick system, and the M_3 M_4 M_3 is the window wall system.

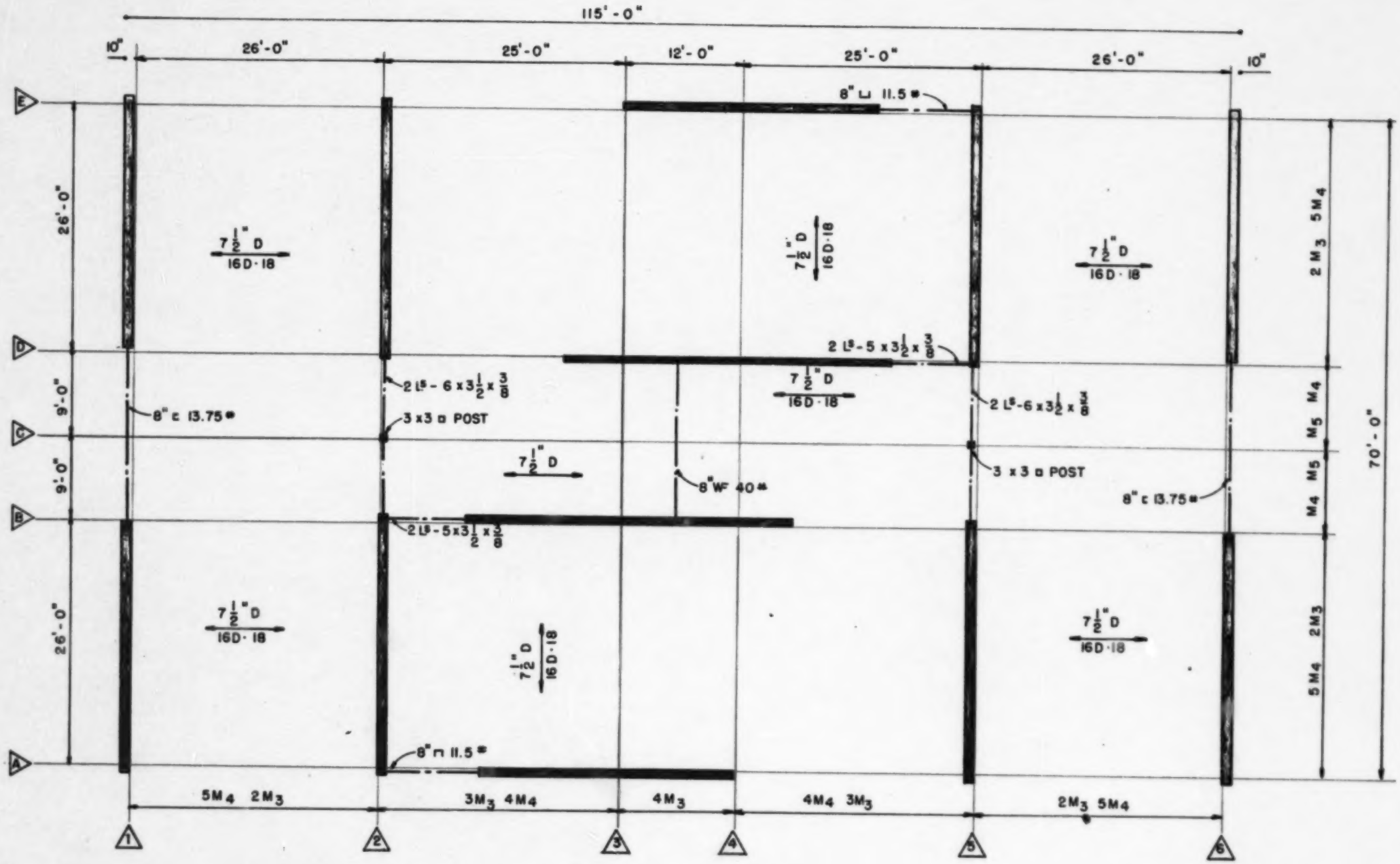


FIGURE 24 STRUCTURAL PLAN: VERTICAL AND ROOF ELEMENTS

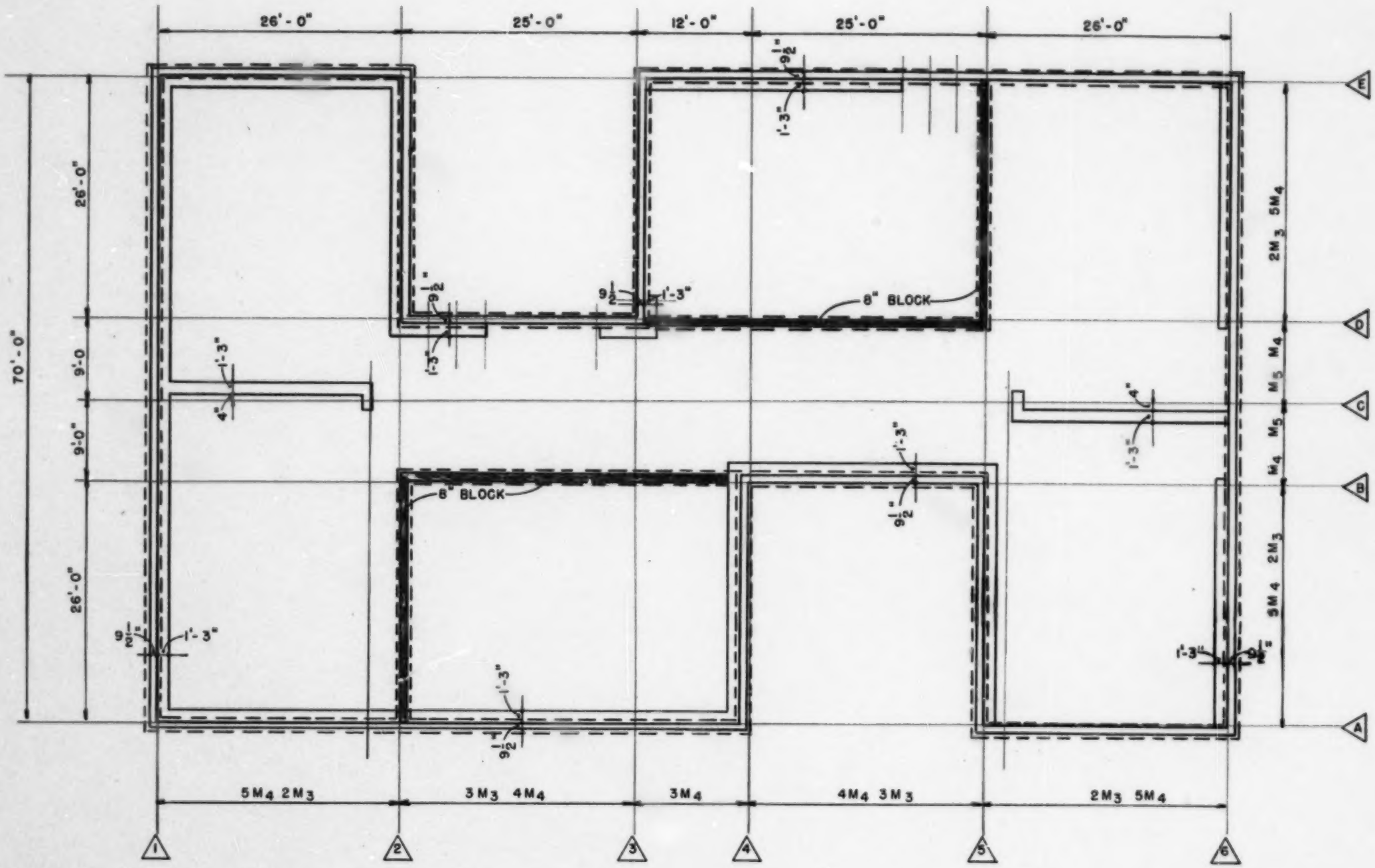


FIGURE 25 STRUCTURAL PLAN: CONCRETE FLOOR AND FOUNDATION

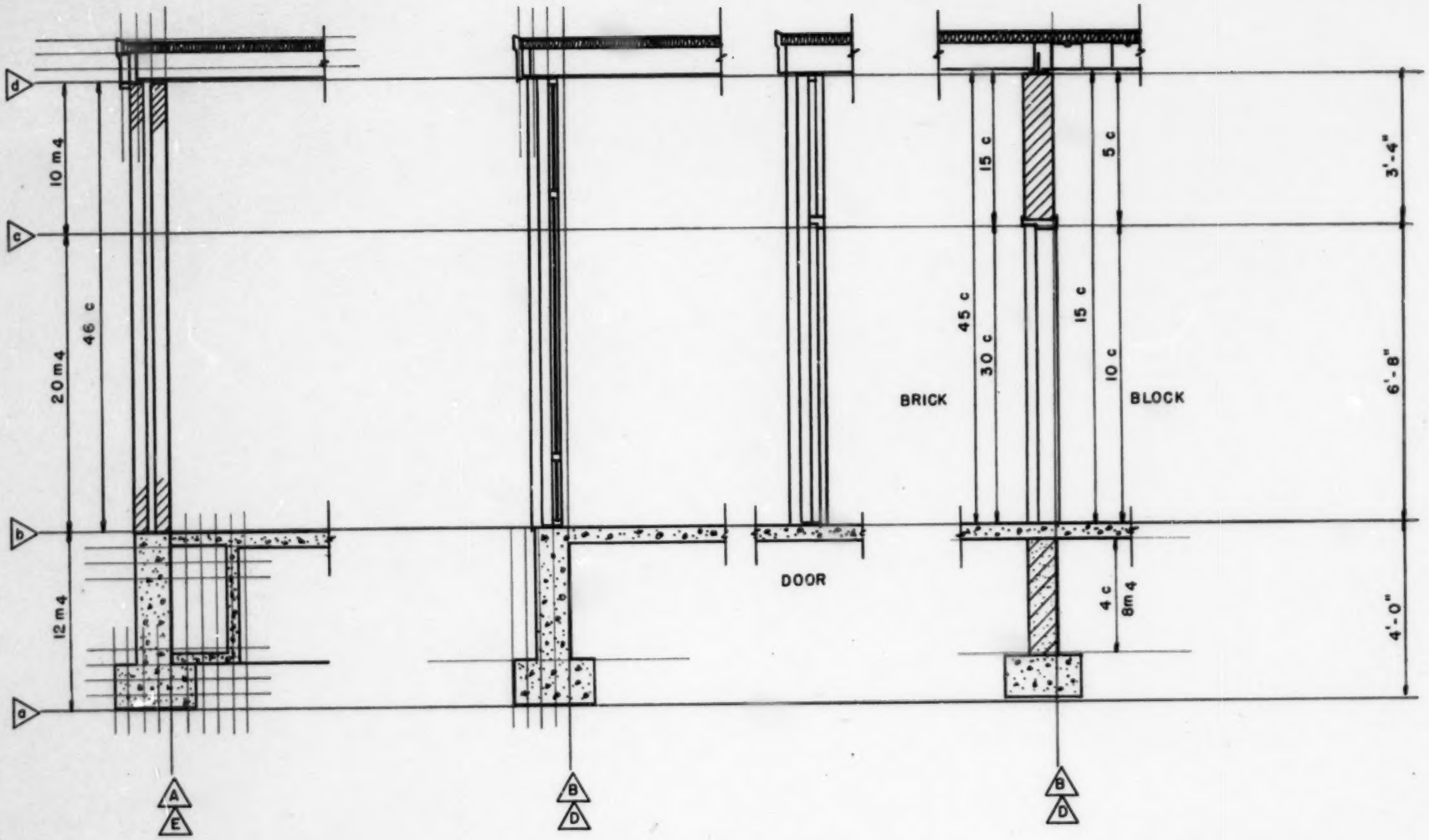
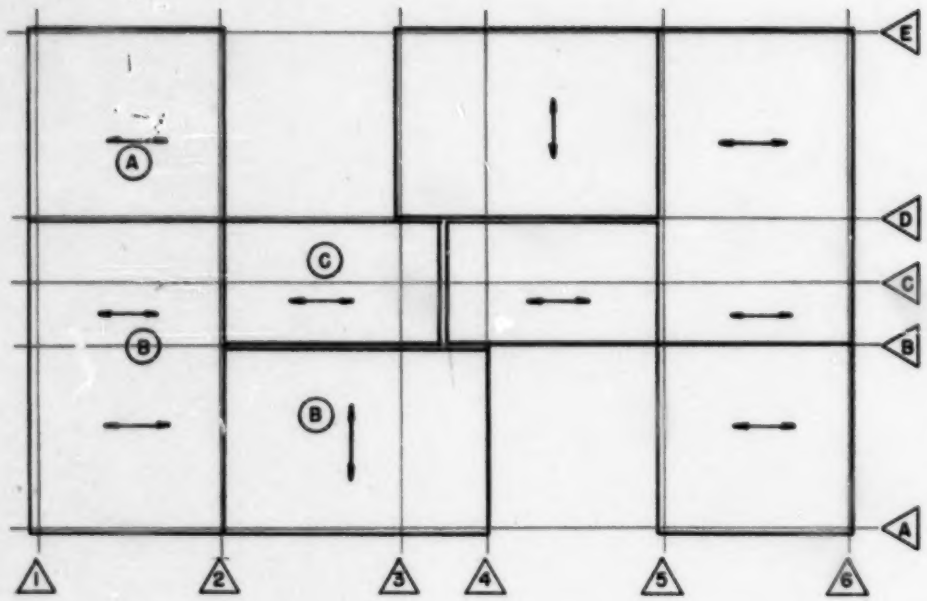
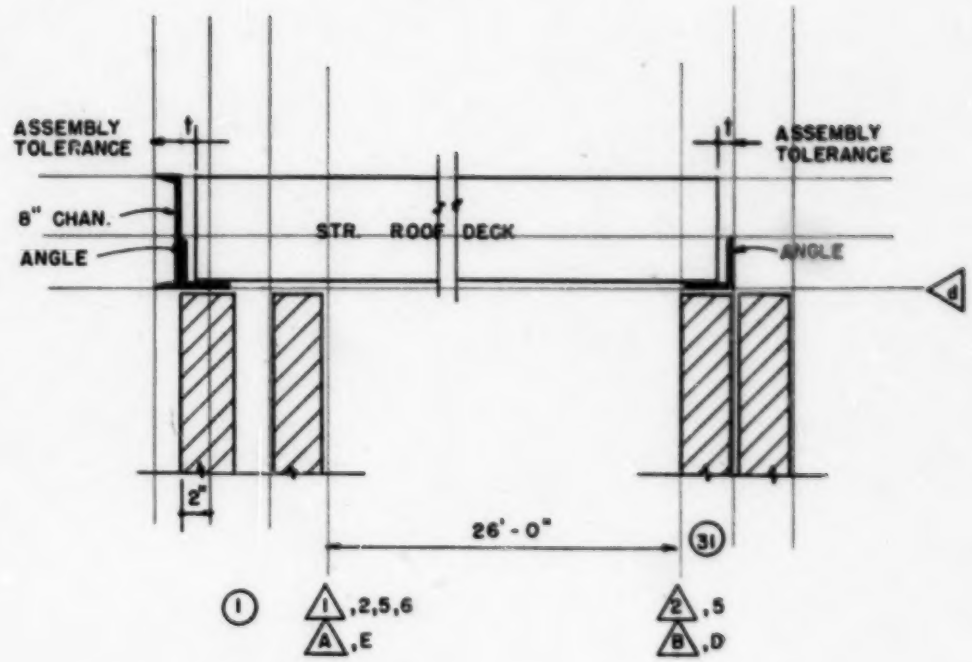


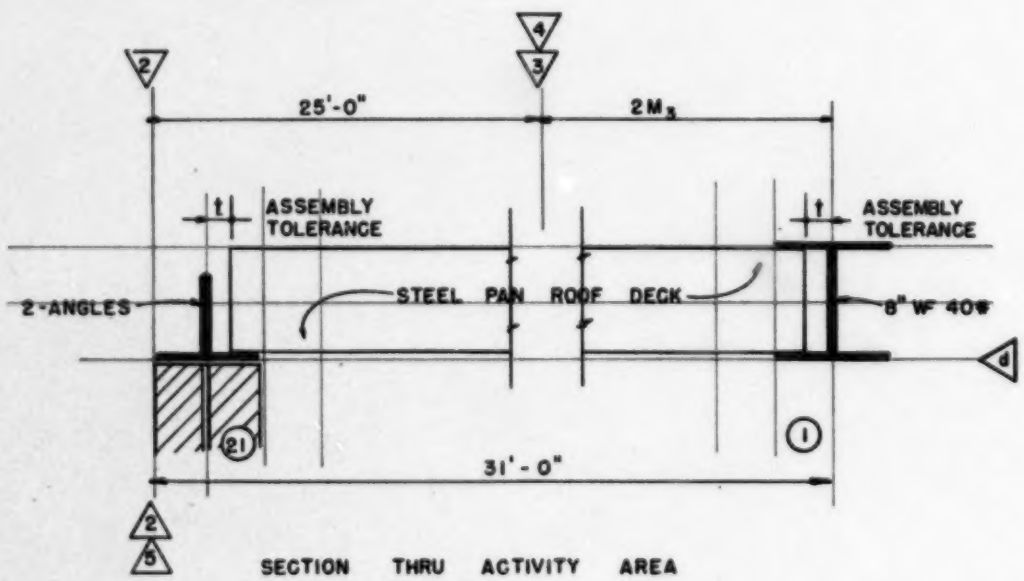
FIGURE 26 TYPICAL SECTIONS



PLAN - ROOF STRUCTURE



TYPICAL SECTION



SECTION THRU ACTIVITY AREA

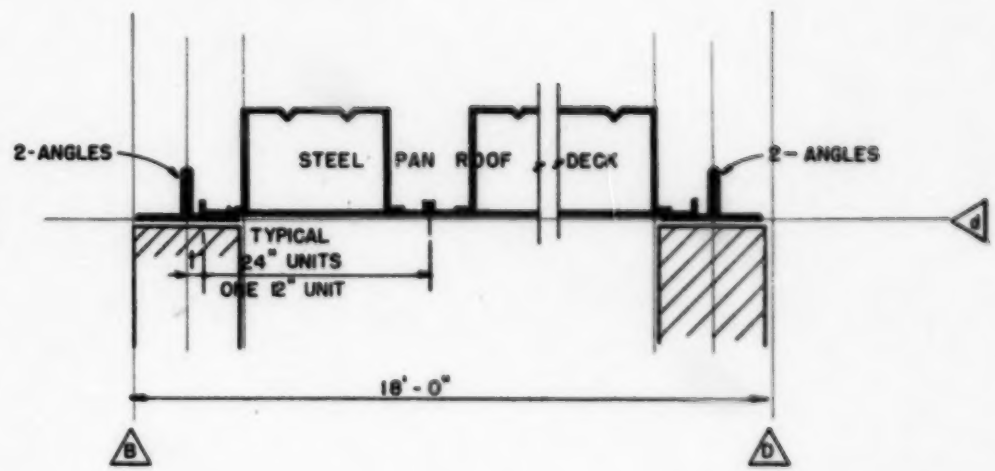


FIGURE 27 STRUCTURAL ELEMENTS: COMPONENTS

TABLE VII LENGTH OF ROOF DECK COMPONENTS

LOCATION	REFERENCE LINES	REFERENCE DIMENSION	END CONDITIONS LEFT CATAGORY & TYPE	LEFT INCREMENT	LEFT DECREMENT	LEFT t	RIGHT CATAGORY & TYPE	RIGHT INCREMENT	RIGHT DECREMENT	RIGHT t
A	1 2	26'-0"	33	$3m_4$	–	3	33	$3m_4$	–	3
	MODULAR LENGTH = 26'-0" + $3m_4$ + $3m_4$ = 28'-0" ACTUAL LENGTH = 28'-0" – Σt = 27'-6"									
B	A B	26'-0"	33	$3m_4$	–	3	31	m_4	–	1
	MODULAR LENGTH = 26'-0 + $3m_4$ + m_4 = 27'-4" ACTUAL LENGTH = 27'-4" – Σt = 27'-0"									
C	2 3 +$2M_3$	31'-0"	21	–	m_4	1	1	–	–	2
	MODULAR LENGTH = 31'-0" – m = 30'-8" ACTUAL LENGTH = 30'-8" – Σt = 30'-5"									

Vertically, both material systems must correlate dimensionally between principal reference planes ◁b▷ and ◁d▷ and to a height of $30m_4$. The brick material system employed has a bidimensional range of material size (R) of $2m_4$ in elevation view. When assembled into its own system the individual brick size of 2-1/4" by 7-5/8", gives within the range reference grid of this material system a three tier coursing by a single length, shown in Figure 29. This material with its joint system, therefore, is represented by a square grid pattern of $2m_4$ by $2m_4$. Thus, within a square frame of reference M_4, 36 bidimensional Rs or a horizontal run of 6 ($2m_4$) and a vertical run of 6 ($2m_4$) correlate. Since there is a three tier coursing per $2m_4$ by $2m_4$, the number of bricks would be equal to 3 x 36 or 108 bricks per m_4 layer or 216 bricks per $2m_4$ layer. In applying this particular range of material size to the exterior wall of $79m_4$ by $30m_4$, using a running bond, the masonry contractor and tradesman may determine immediately the extent of brickwork, the exact number of bricks and the specific location of every brick.

The other material system within the exterior wall element, the window wall, follows a rhythmical repetitive grid pattern, established during element modulation. The dimensional reference pattern describes four types of unit. These, as shown in Figure 28 are:

Type	Description	Width Refer. Grid	Dimen. Feet	Height Refer. Grid	Integer Coef's	Dimen. Inch
1	Fixed	M_3	3	m_4	5 + 17 + 8 = 30	120
2	Operable	M_3 M_4	7	m_4	6 + 14 + 10 = 30	120
3	Fixed	$2M_3$	6	m_4	5 + 14 + 8 = 30	120
4	Door	$2M_3$	6	m_4	20 + 10 = 30	120

The window wall subcontractor can submit to the manufacturer the reference grids as established by the architect's wall element modulation reference pattern. The fabricator in turn furnishes the stock components or produces the various components comprising the window wall in accordance with the dimensions of the reference grids. The range of sizes of components are thus correlated dimensionally with the window wall reference grids. The fabricator provides for the manufacturing and fabricating tolerances. By knowing the particular component material and the reference grids, the dimensions of all components may be immediately established.

If the reference grid ranges are known, all suppliers of subcomponent material may keep in stock such material as furnished to the window wall fabricator. For example, Figure 28 shows the reference grid for sash Type 1. All assembly details hold for the 4 types of window wall units in this school building design. Thus, the manufacturer furnishing panels for Types 1, 2, and 3 knows that the width reference grids for these types are:

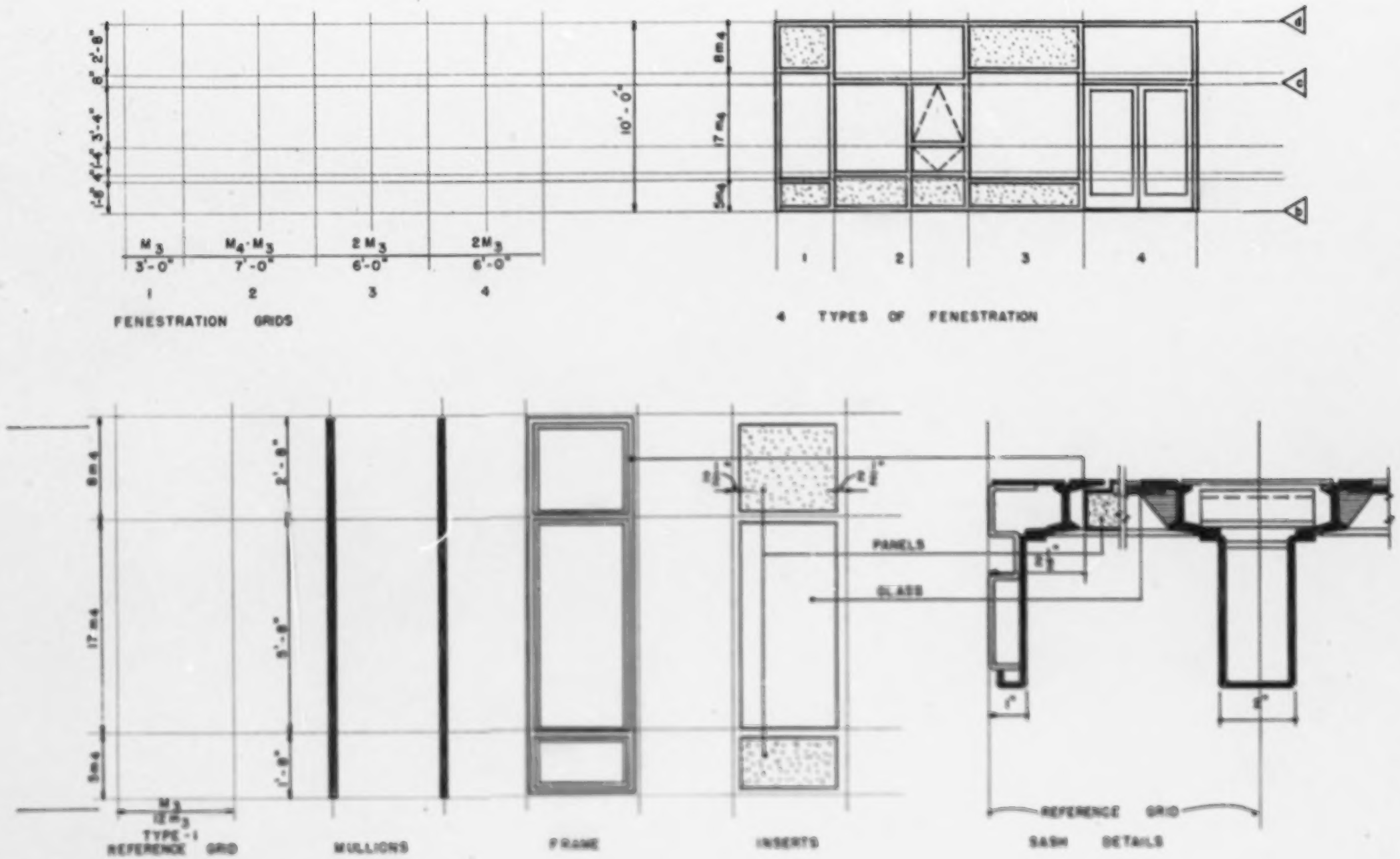


FIGURE 28 MATERIAL SYSTEMS: EXTERIOR WALLS

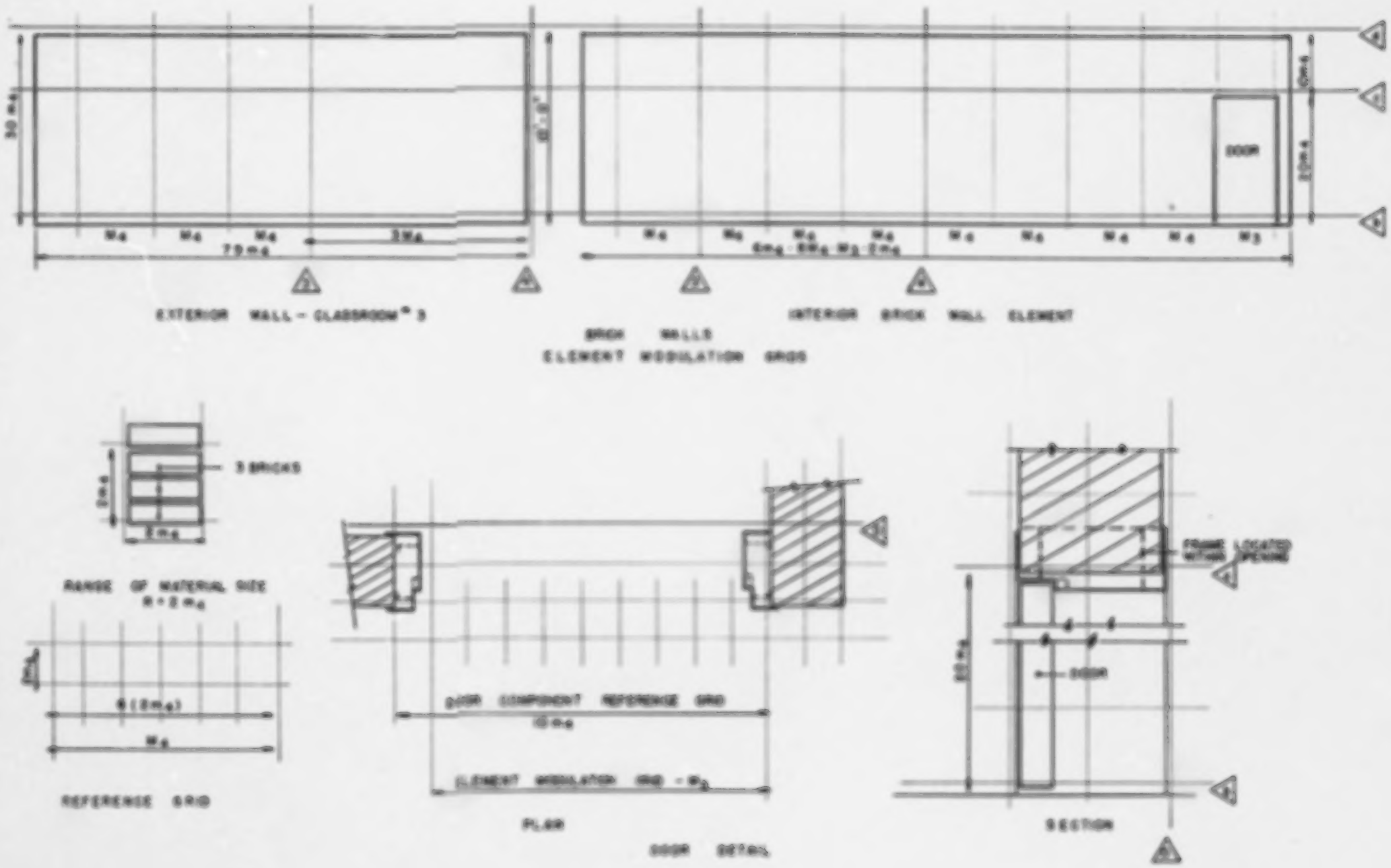


FIGURE 29 MATERIAL SYSTEMS: COMPONENTS

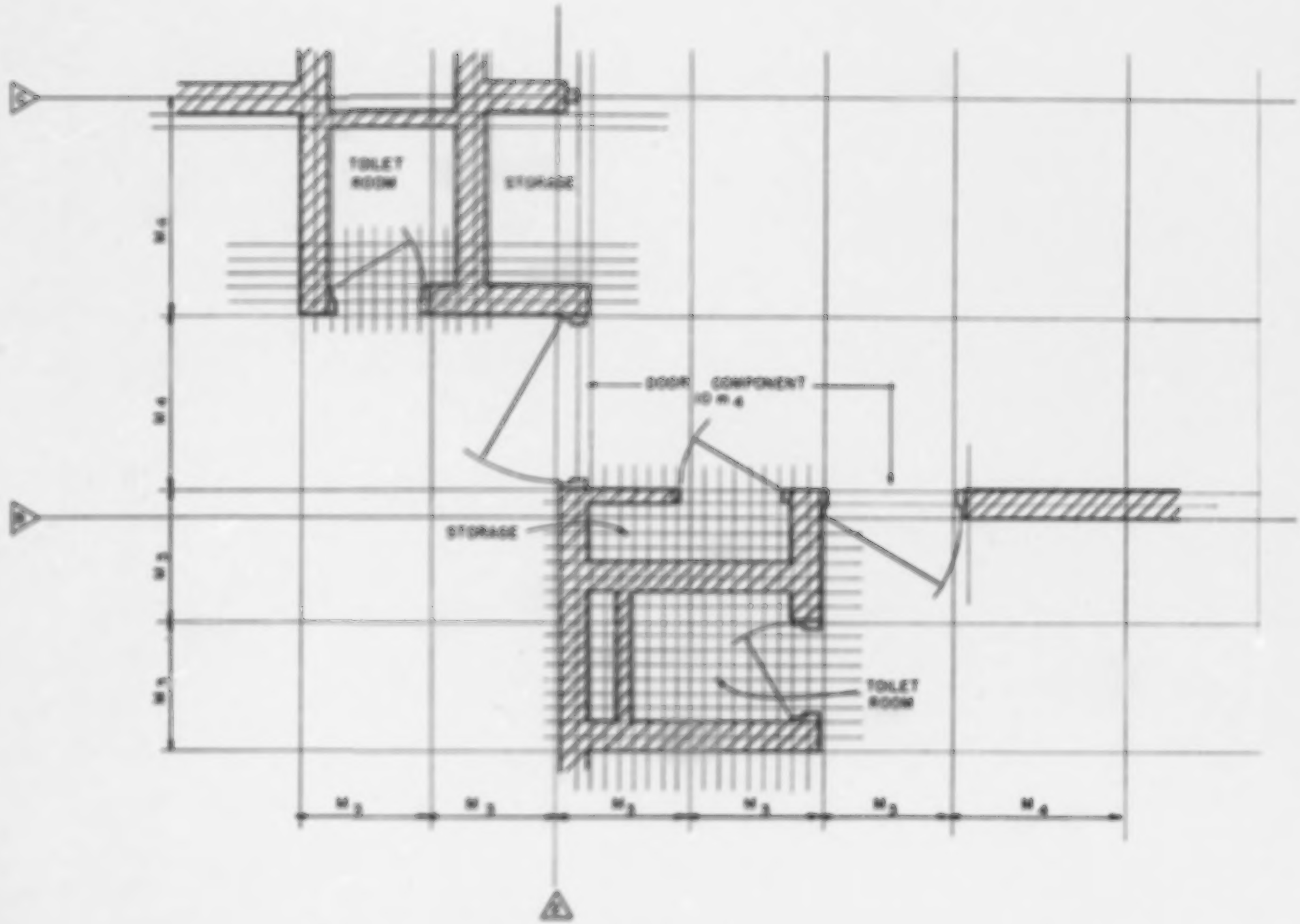


FIGURE 30 LARGE SCALE PLAN

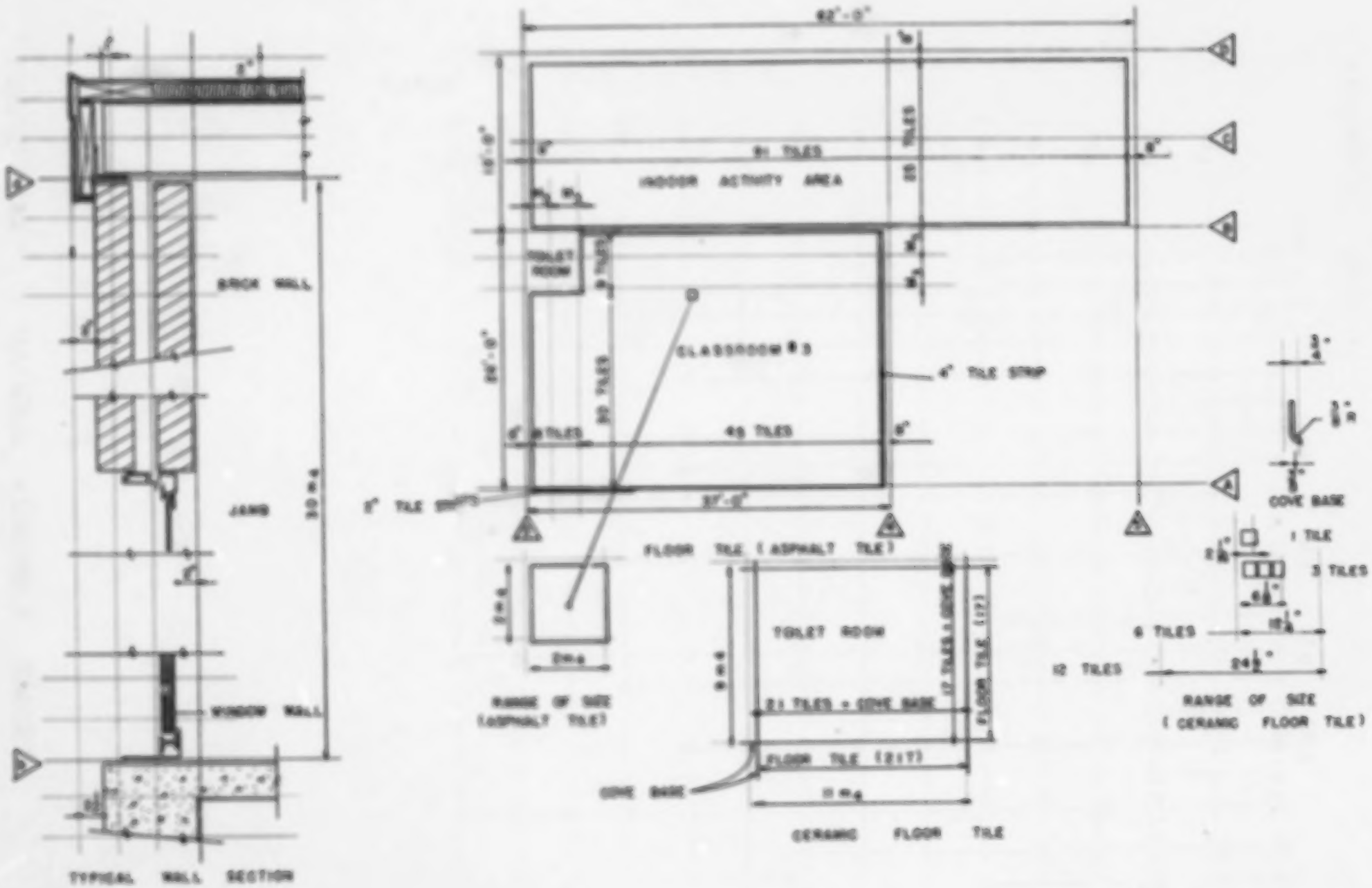
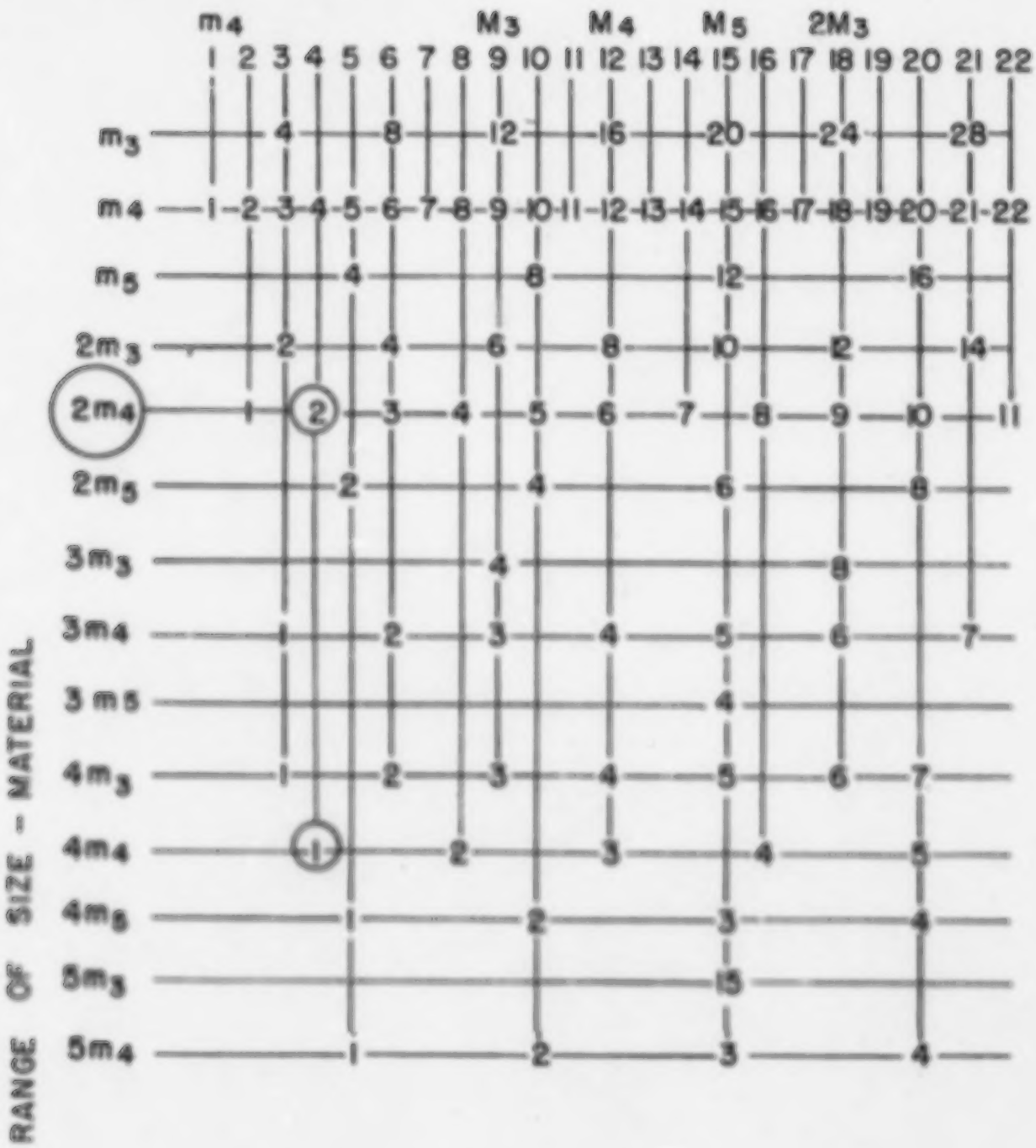


FIGURE 31 ELEMENT COORDINATION

REFERENCE GRIDS *



* BASED ON m_4 ONLY

FIGURE 32 MATERIAL ASSEMBLY RANGES

Type 1	M_3
Type 2	$M_4 + M_3$
Type 3	$2M_3$

He also knows that the offset for finish mold, frame and tolerance is 2-1/2" in each case. The manufacturing dimensions in the width direction for these insert panels are, therefore, respectively 31", 79", and 67". Similar conditions would hold true for the vertical dimensions.

Single Components

Individual components are considered in a similar manner, i. e. as simple subelements within a complex element. The component itself has its own reference grid which is determined by its function, size, detail design, and material composition. The function and material composition are set factors. The size, however, and detail design of these components may vary or may be offered in a variety of sizes and shapes within a particular range.

A door is a representative example of a building component, including not only the door proper but also the frame, trim, and all other associated parts. The function of the component and of its parts is known, along with the materials of which they are made. The size of the door leaf and the size of the frame will vary depending upon the range of sizes of door openings, and upon the specific application of the trim to particular element material systems. The entire assembly has a reference grid. Reference grid ranges are shown in Figure 32.

A door component reference grid is shown in Figure 29. For the particular door opening requirement of 3'-0" and located within the interior brick wall element, the door with its frame has a reference grid of $10m_4$ by $20m_4$. The frame may overlap the brick wall opening or may be located entirely within the opening. These *are individual design details affecting the frame and/or trim and do not alter the* reference grid for this component.

The interior brick wall element within which the door component is to be placed is modulated, considering of course the material systems comprising the element. The resultant modulation is: $6m_4$ $8M_4$ M_3 $2m_4$. The door reference grid which correlates or meshes with the line common to the M_3 and $2m_4$ grid is $10m_4$. This is compatible with the range of material size of $2m_4$ of the brick system. Similarly is this true with the vertical correlation. The $20m_4$ door reference grid is also compatible with the $2m_4$ brick material range size, so that the vertical placement of the door is between the principal planning reference lines ◁ and ◁ or $20m_4$. Since the wall element modulation is carried out for the element material system of brick and also the reference grids for both the brick and the door component, there is compatibility and correlation with the common reference grid. In addition, the detail indicates coordination of the door component placement and size within the element. The material range of sizes are shown in Figure 32.

The door component has its own reference grid of $10m_4$ by $20m_4$. The manufacturer's consideration of the frames (whether they are to fit within the opening in the element or wrap around) will set the various designs or stock items offered. The actual door dimensions are referenced to the grid with various allowances for trim offset and assembly tolerances. All related dimensions are set for both the frame and door and will be derived from the door component reference grids. With this information, the designer can coordinate door components into the elements by detail design.

Element Coordination

Element coordination is achieved through several steps within the modular system. The first step evolves from the initial space modulation and creates reference planes to which the materials and elements will be positioned. These planes remain as a coordinating medium by which elements and materials are related dimensionally. The selection of the particular modulation is conditioned not only by the space disposition but also by the various elements and the material systems comprising them. With the space modulation set, the element positioning is adjusted for material range of sizes and for component disposition.

Figure 30 shows a large scale plan for the toilet-storage room area of the school plan where maximum element coordination is necessary. The first step in coordination is evidenced by the three principal reference planes B, C, and Z which are shown in red. Additional planes of dimensional reference are the grid lines resulting from modulation and shown in blue. These are the lines for which spacing is denoted as M_3, M_4 or M_5. In effecting element coordination proceeding from small scale to detail (large scale) drawings, the area and detail representation runs conversely, from large to small. In the small scale plans and elevations, therefore, only the principal reference planes are shown as grid lines for over-all dimensional correlation. For the large scale details, however, and particular area plans, the modulation grids are shown. The small modular grid of m_4 is shown for this area.

In this example the major elements follow the modulation grids either as their centerline or as the nominal face of these elements. The carcass or finish material is brick, except for the toilet rooms where ceramic tile is used as a finish. Since brick is used for the major portion of elements, this material not only influenced element modulation but also determined the selection of m_4 as the basic module, which is compatible or correlates with the material reference grid for the brick of $2m_4$, another coordinating medium. Since the brick material elements are positioned along and within the basic module grid lines and have a material reference grid pattern comprising the basic m_4 module, their meeting and intersection are coordinated.

As illustrated previously, the door components likewise coordinate with the brick wall element because they are positioned to a space modulation reference grid by the basic m_4 reference module. Furthermore, their component reference grid is

a multiple of the basic module and also a multiple of the material reference grid of the element. The component, therefore, coordinates within the element.

One condition where a finish material element system must coordinate with the carcass material element is shown in Figure 31. Here the carcass wall elements are positioned within the basic m_4 reference grids. The floor area grid pattern is represented as $9m_4$ by $11m_4$. Since a 3/8" radius cove base was selected for use at the intersection of the finished floor and the four walls, the assembly dimension of the base (3/4") must be doubled and would equal 1-1/2". Thus, the total nominal area receiving the tile finish is 34-1/2" by 42-1/2". Although the ceramic tile material grid pattern is based upon the size of one tile as a 2" square, the grid pattern including assembly tolerance is provided by the manufacturer as follows:

No. of Titles	Grid
1	2-1/16
6	12-1/4
12	24-1/2

Obviously, a simple dimensional system was not the basis for establishing the sizes of individual units or subassemblies. It is possible that the dimensional characteristics were accumulated on the basis of a component subassembly consisting of six units by twelve units. This material system might be considered nonmodular. It is possible, however, to coordinate this tile material system at the element intersections in more than one way. In this case the cove detail, material systems, component assembly characteristics and actual dimensions must have inherent flexibility so that assembly can be achieved with ease. The one solution illustrated shows that the number of tile units needed to accomplish this is 17 by 21. A comparison of the actual over-all clearance dimensions versus the over-all assembly dimensions verifies coordination, i.e. 36-3/8" by 44-3/8" versus 36-3/16" by 44-3/8". For all practical purposes the tile setter must expand the 20 joints in the nominal 36" direction so that up to 3/16" can be gained. The tradesman likewise must contract, if required, the 24 joints in the nominal 44" direction. Thus, a skillful mechanic is able to make the installation without cutting tile.

Figure 31 shows the coordination of a finish floor material system, such as asphalt tile, in the typical Classroom Number 3 and in the Indoor Activity Area. The finish material system reference pattern of $2m_4$ was selected because it coordinates with the classroom wall elements. Areas at the window subelements and the door component are coordinated by the use of a particular design detail. This description illustrates the final use of the modular method as related to element coordination, i. e. details of design. The typical wall section shown in Figure 31 illustrates the procedure described.

The design and specific placement of material systems and their compatible intersection and parallel which overlap or butt within the modular frames of dimensional reference, may be controlled and set by design by the architect to achieve coordination.

Example Number Two: A fourteen classroom elementary school with one kindergarten located on a 13-acre site, designed by Cram and Ferguson, Architects.

Design

The particular program of this school required space for 450 pupils in grades one through six and a kindergarten for 40 additional pupils. Administrative spaces, regular and special classrooms, the necessary toilet rooms, storage areas, and an all-purpose room with adjacent kitchen were provided. The disposition of space resulted in a school plant of a two-story classroom block with a one-story wing for the kindergarten and an administrative and recreation wing.

The structure has a thin concrete floor slab over open web joists which rest on hot rolled steel sections. The first floor slab is supported by piers. The vertical structure consists of lally columns resting on a concrete foundation and footings. The fenestration generally is accomplished by strip windows which extend from a particular sill height to the classroom ceiling finish. Services and piping are furnished through a pipe tunnel just inside the periphery foundation wall of the building and run vertically through chases.

Preliminary Design

Figures 33, 34, 35 and 36 represent the final preliminary drawings submitted by the architect and approved by the school board as the owner. These are drawn to scale and include space designation, room sizes and over-all dimensions. They also serve to obtain preliminary cost estimates and tentative approval from the owner.

Reference Frame and Space Modulation

Figures 37, 38, 39 and 40 represent part of the contract working drawing set prepared by the architect. Since the second floor plan is substantially the same as the first floor, it is not included.

After the usual detail studies are accomplished by the designers, the principal planes of reference are established. These are the main reference planes which are set by the architect at precise locations influenced by mass configuration, change in element system, elevation differentials, etc. These planes are shown in drawings, elevation and section as lines and are indicated in red on the accompanying figures. The lines are identified by numerals or letters in bold triangles. The positioning of these reference planes as related to each other is established by a dimensional relationship resulting from space modulation. For example, the position of reference plane 9 with respect to 7 is $21M_4$ or 84'-0". The particular modulation selected in this instance was influenced by the spaces, classrooms of 36'-0" lengths, fenestration subelement, structural element and the stair hall of essentially a 12'-0" width. The M_4 modulation sequence was compatible with the

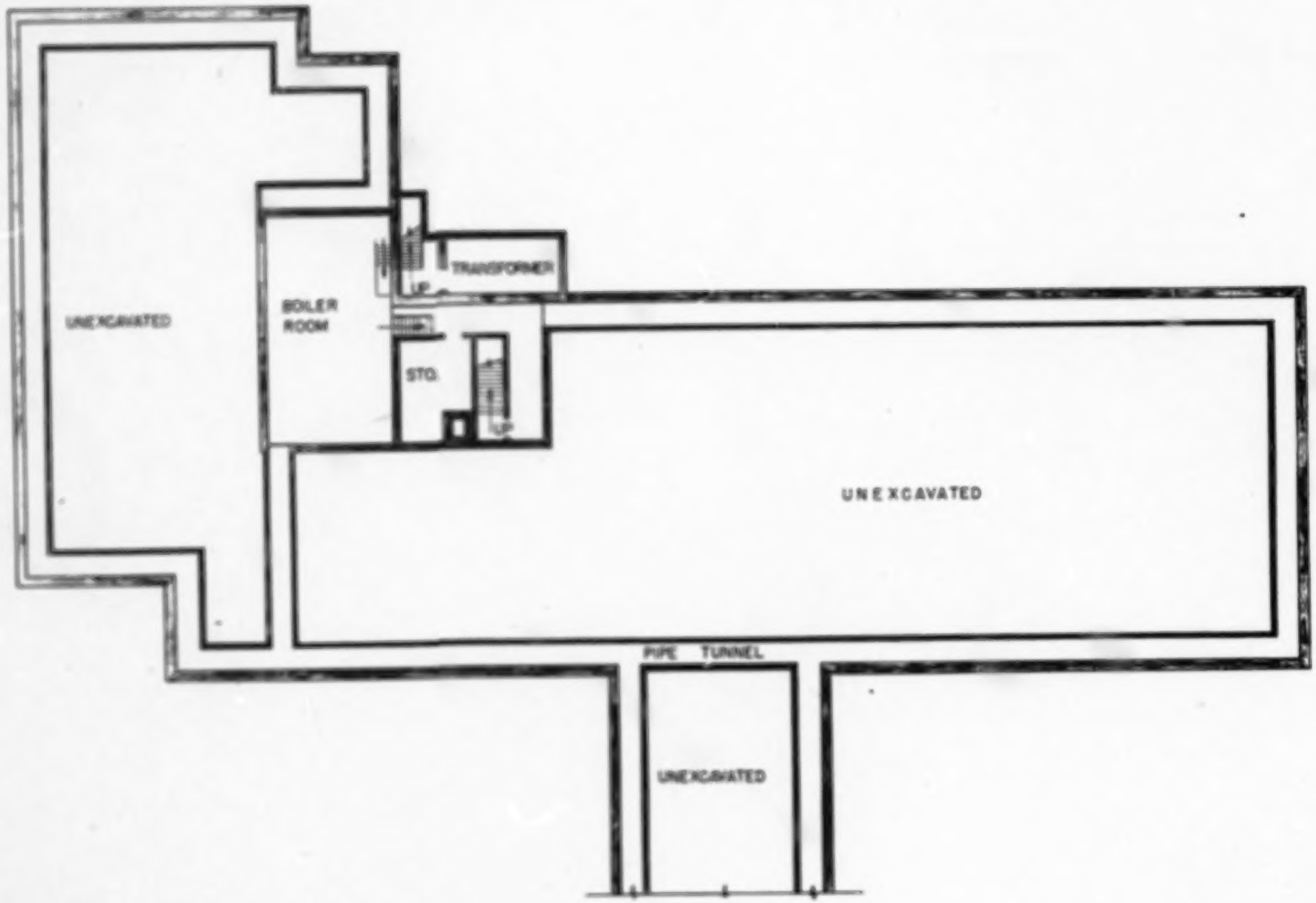


FIGURE 33 PRELIMINARY DESIGN PLAN BASEMENT

FIGURE 34 PRELIMINARY DESIGN: PLAN FIRST FLOOR

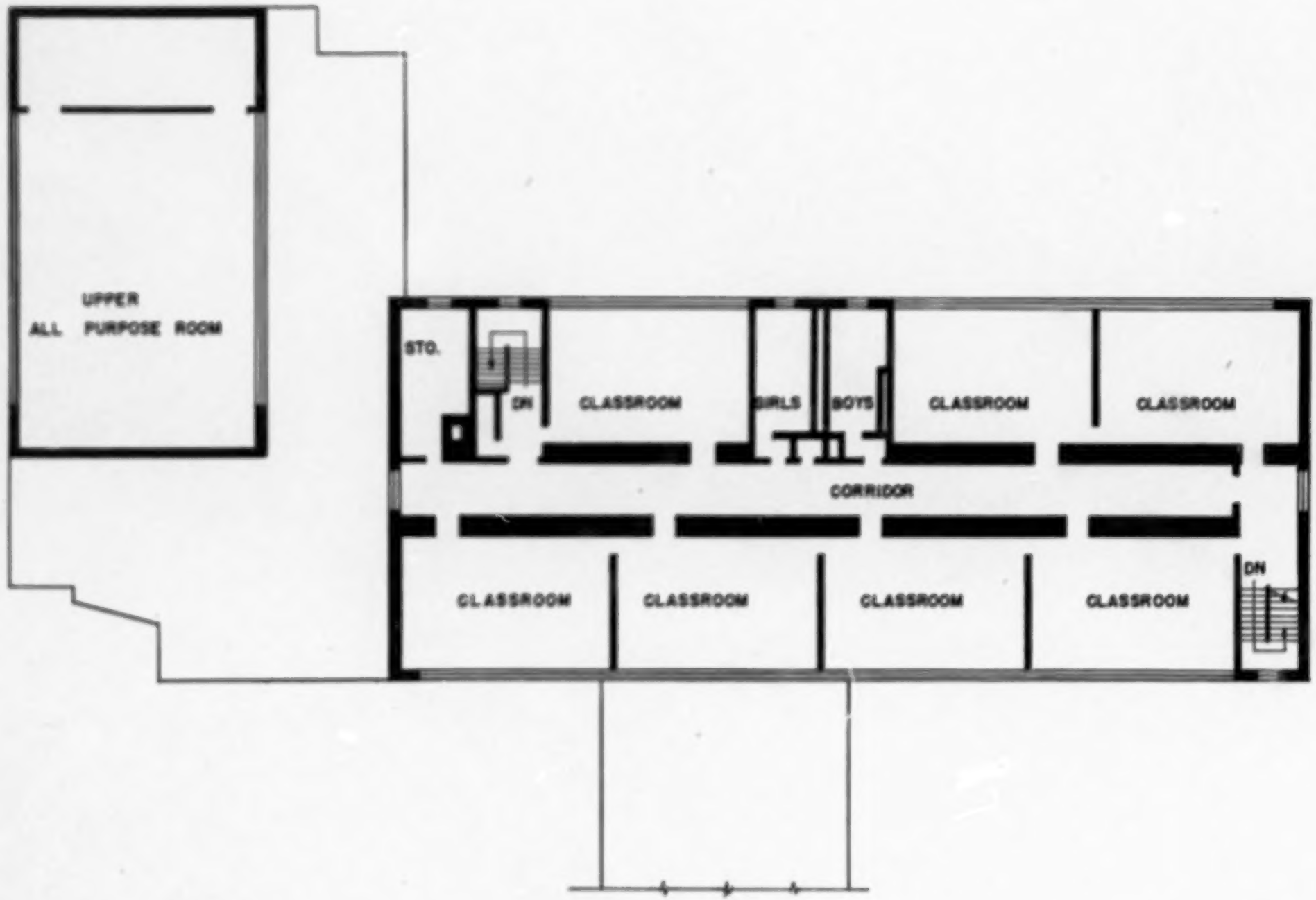
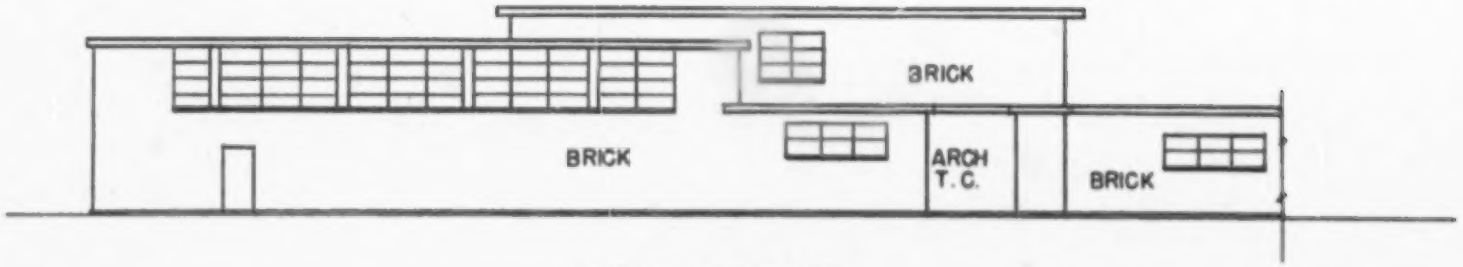
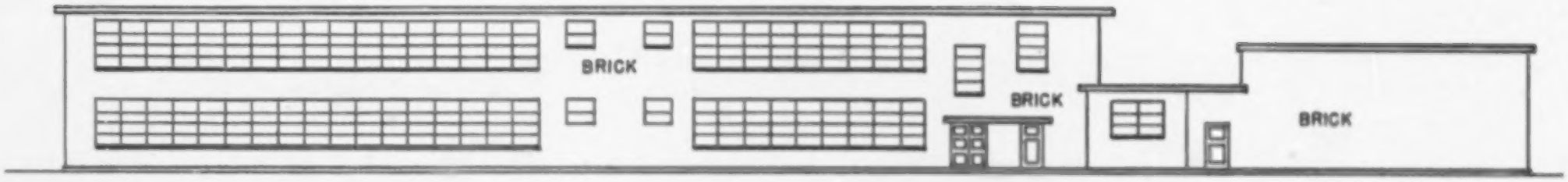


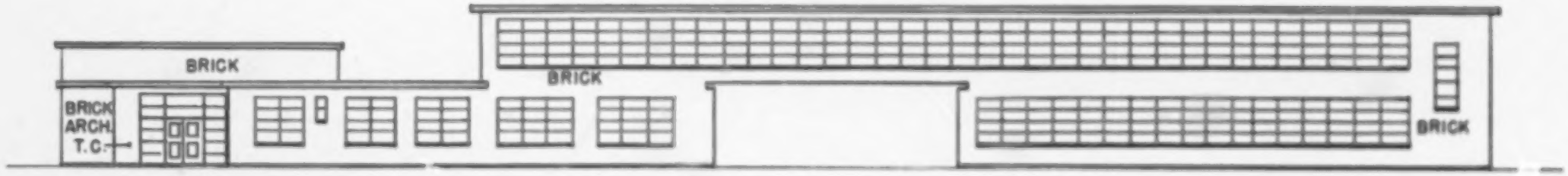
FIGURE 35 PRELIMINARY DESIGN: SECOND FLOOR PLAN



NORTH ELEVATION



EAST ELEVATION



WEST ELEVATION

FIGURE 36 PRELIMINARY DESIGN: ELEVATIONS

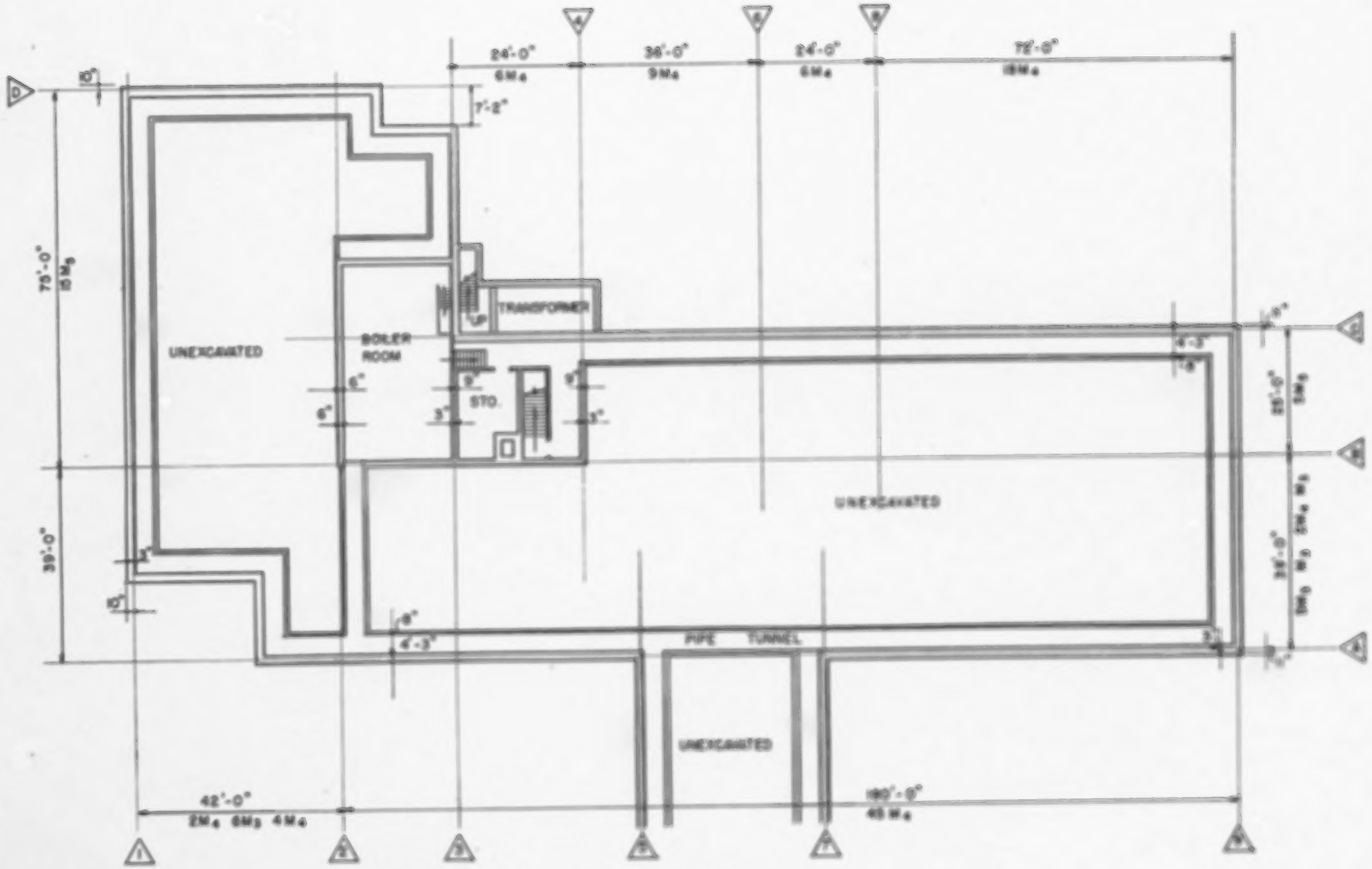


FIGURE 37 REFERENCE FRAME AND SPACE MODULATION: PLAN BASEMENT

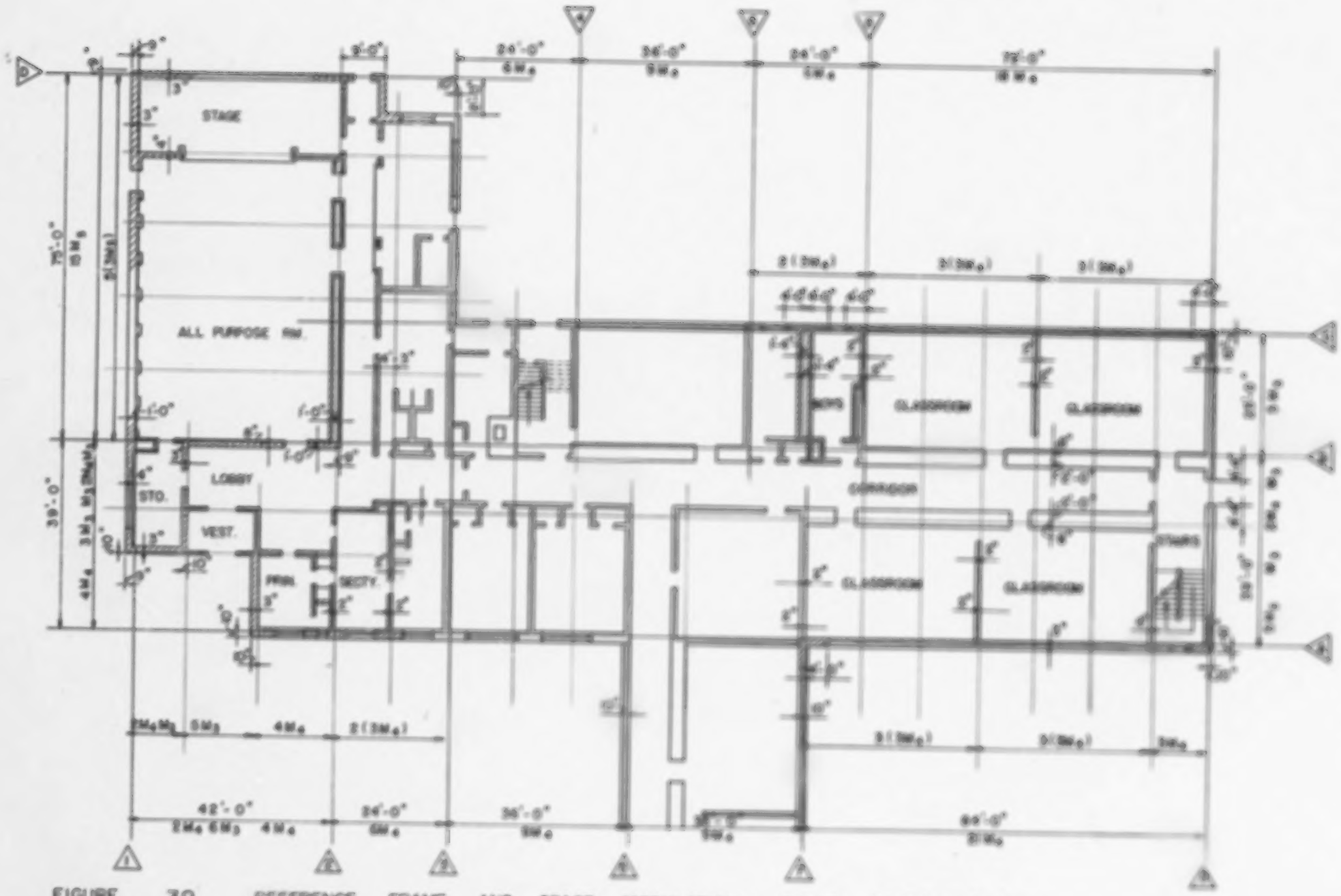


FIGURE 38 REFERENCE FRAME AND SPACE MODULATION: FIRST FLOOR PLAN

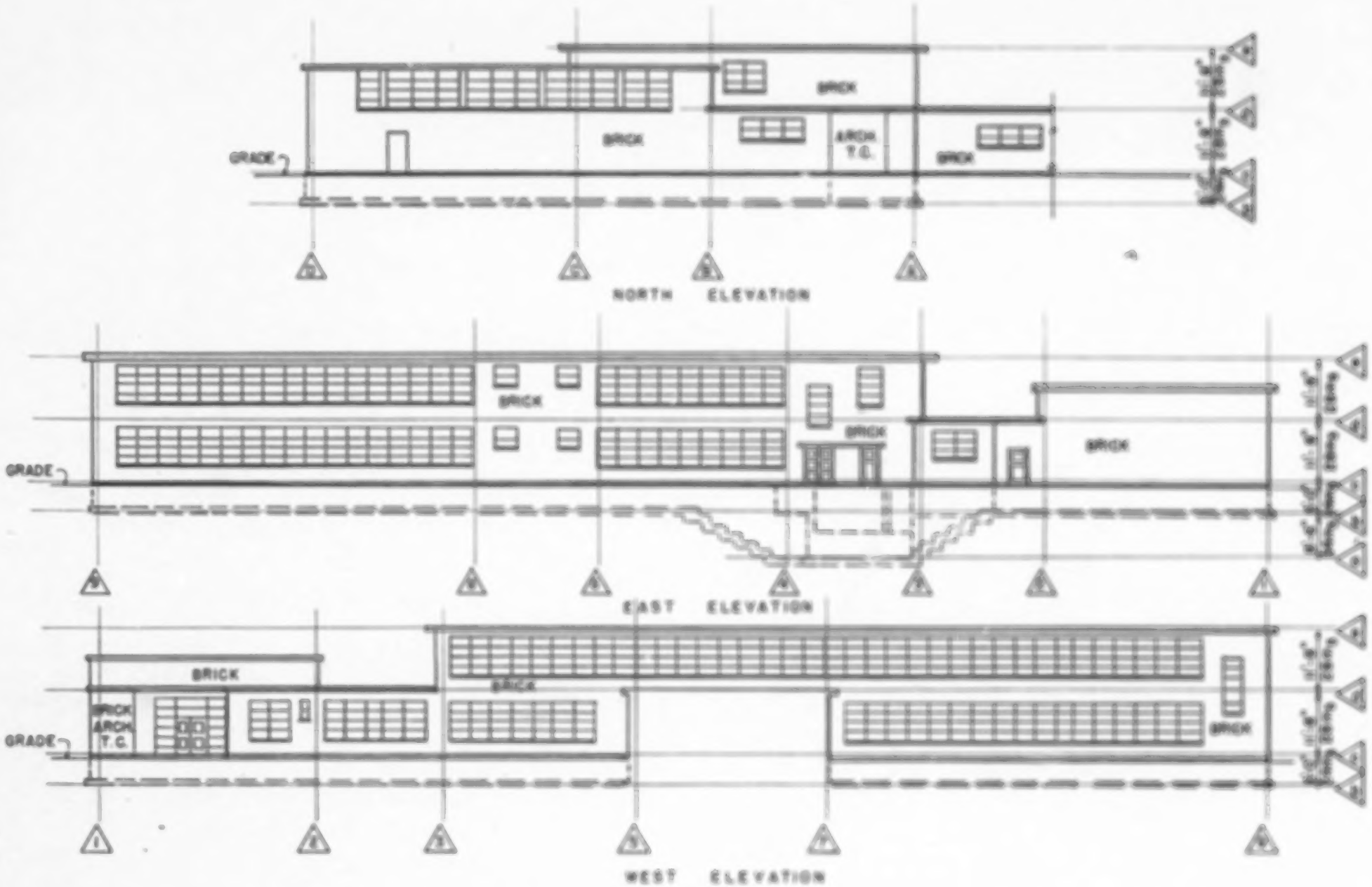


FIGURE 39 REFERENCE FRAME AND SPACE MODULATION: ELEVATIONS

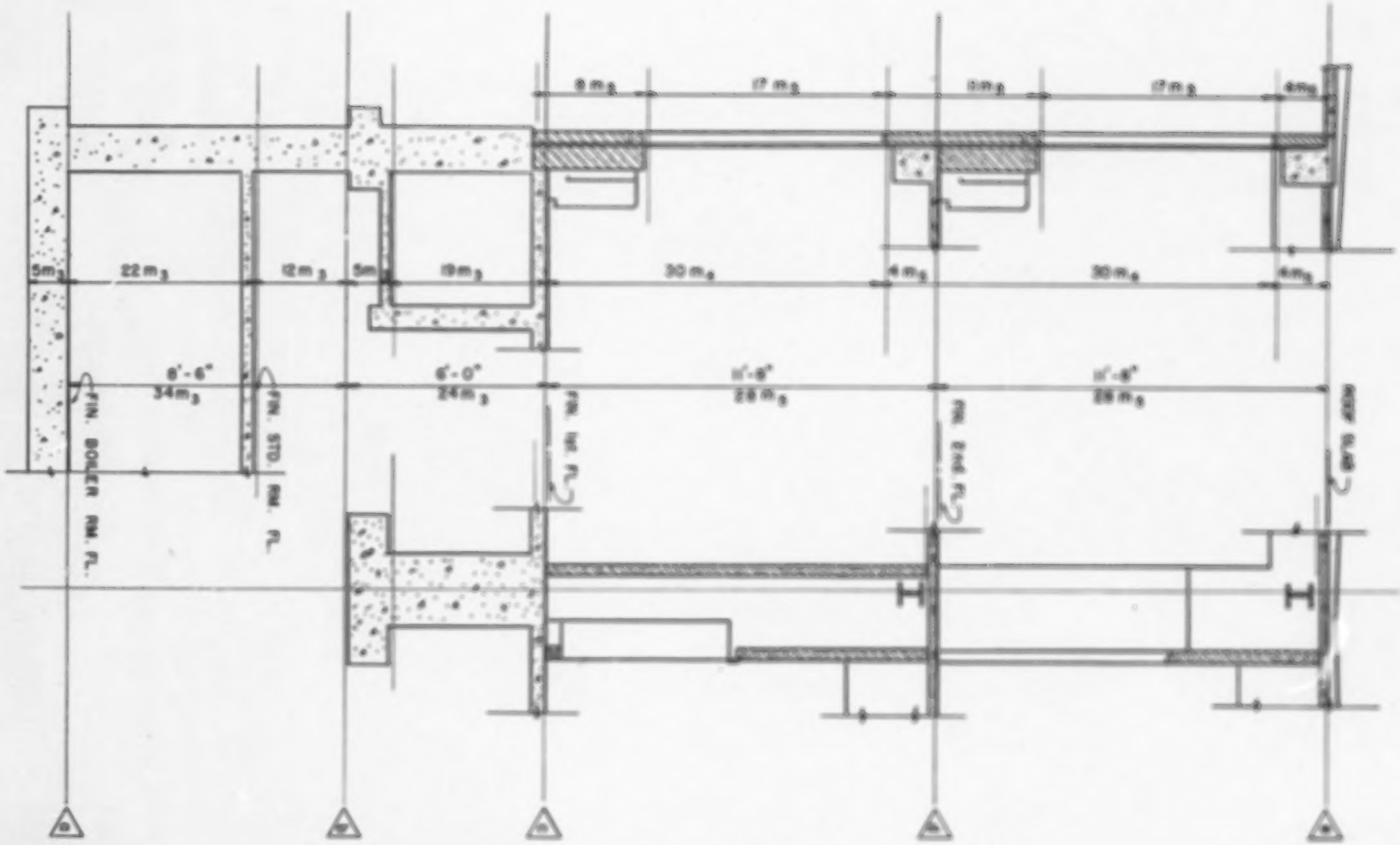


FIGURE 40 REFERENCE FRAME AND SPACE MODULATION: SECTION

dimensional limitations of these areas and elements. The space modulation on the plan is expressed in large M. The principal planes of reference are dimensionally related to each other by a space modulation expressed by some appropriate sequence of M_3, M_4 and/or M_5.

Reference grids resulting from the space modulation are also shown on the plans, elevations and sections, as required for dimensional reference of building elements. For example, in the classroom area of Figure 37, the M_4 is grouped into $3M_4$, which in turn is grouped as 3 ($3M_4$). The location of building elements and the extent of the fenestration is indicated by dimensioning to these modulation grids or to the reference frame.

In establishing the horizontal principal planes of reference which show in the elevation and section drawings, Figures 39 and 40 respectively, the space between planes is modulated in this case on the small m basis. Thus, the principal planes are placed at the first and second floor slab elevations, are identified as △c and △d and are spaced $28m_5$ apart. Similarly, the plane at the roof slab is $28m_5$ above the second floor reference frame. The m_5 modulation was selected here because of its dimensional compatibility with the range of size of the exterior wall material, the concrete slabs, the secondary structural elements, and the sill and space heights as shown in Figure 40.

Structural Element

The structural drawings (Figures 41, 42, and 43) are a part of the contract set and are the responsibility of both the architect and engineer. The particular system and materials were adopted and detailed as shown on these drawings. The reference frame is the same as shown in red on the architectural drawings and identified by numerals and letters in bold triangles. The reference planes or grids resulting from modulation are shown in blue, and are grouped to identify the location of the major structural members. These grids are also marked with letters and numerals in bold circles. The grids so marked are the centerlines of columns or piers. All dimensions of the structural components are related to these grids and to those of the reference frame. Also any openings in the floor slabs, depressions of slabs, and the like, are referenced and dimensioned to the grids or to the reference frame.

Wall Element Modulation

The modulation of the exterior wall element which is used by the contractor and the various subcontractors is shown in Figure 44. Here the various subelement systems comprising the wall element are modulated according to their particular material range of size. The masonry subcontractor will base his shop drawings and material take-offs on this drawing and will refer to it during the construction phase of the program. The window subcontractor will make similar use of it for the sash details. The mechanical trade is able to take off the dimensions for the metal ventilation louvers which are compatible with the range of size of surrounding brickwork.

Likewise, the modulation of the interior wall element in the main corridor elevation, as shown in Figure 45, gives the location of all material systems and components. The range of size of the various material systems within the element determine the modulation. The resulting grids, representative of the material systems, mesh at precise locations thus correlating one material or component with another within the multi-material element. This determines the door openings, locker recesses, and ceiling heights as well as the positions for the wall materials. The various contractors concerned may prepare shop drawings and process the installation on the job as guided by these drawings.

Figure 46 shows by detail the coordination of the All-purpose Room exterior wall element with the ceiling and roof structure and with the flooring system. It also shows the positioning of the recesses necessary to allow for the coordination of the recessed table and bench equipment required in this area. It further shows the location of the metal radiator enclosure within the wall element.

Material Components

The two most complicated door details are those leading from the All-purpose Room. The exterior door is in the wall element shown in Figure 46. The door components are coordinated by the architectural detail concerning this particular wall element. Large scale details of these components are shown in Figure 47.

Mechanical Equipment

A portion of the second floor exhaust ducting layout is shown in Figure 48. On the plan the heating engineer dimensions the ducting to the grids which result from modulation and to the reference frame. Utilizing these lines which are identified at the site, the tradesmen install the ducts. Sections 1 and 2 in Figure 48 not only show where the ducting and registers are located within the wall and ceiling elements but also the dimensional relationship of these to the material systems specified for the wall element. The detail in the upper right of the figure is all that is required of a detail to position the ducting within the ceiling system in the main corridor of the school.

Similarly, Figure 49, which represents the layout drawing, shows the location of the plumbing fixtures by dimensionally referencing the fixture drain center-line to the various grids produced by space modulation. The tile or masonry subcontractor and the plumbing subcontractor will refer to this drawing for planning, subassembly and placement of the various materials within these toilet room spaces.

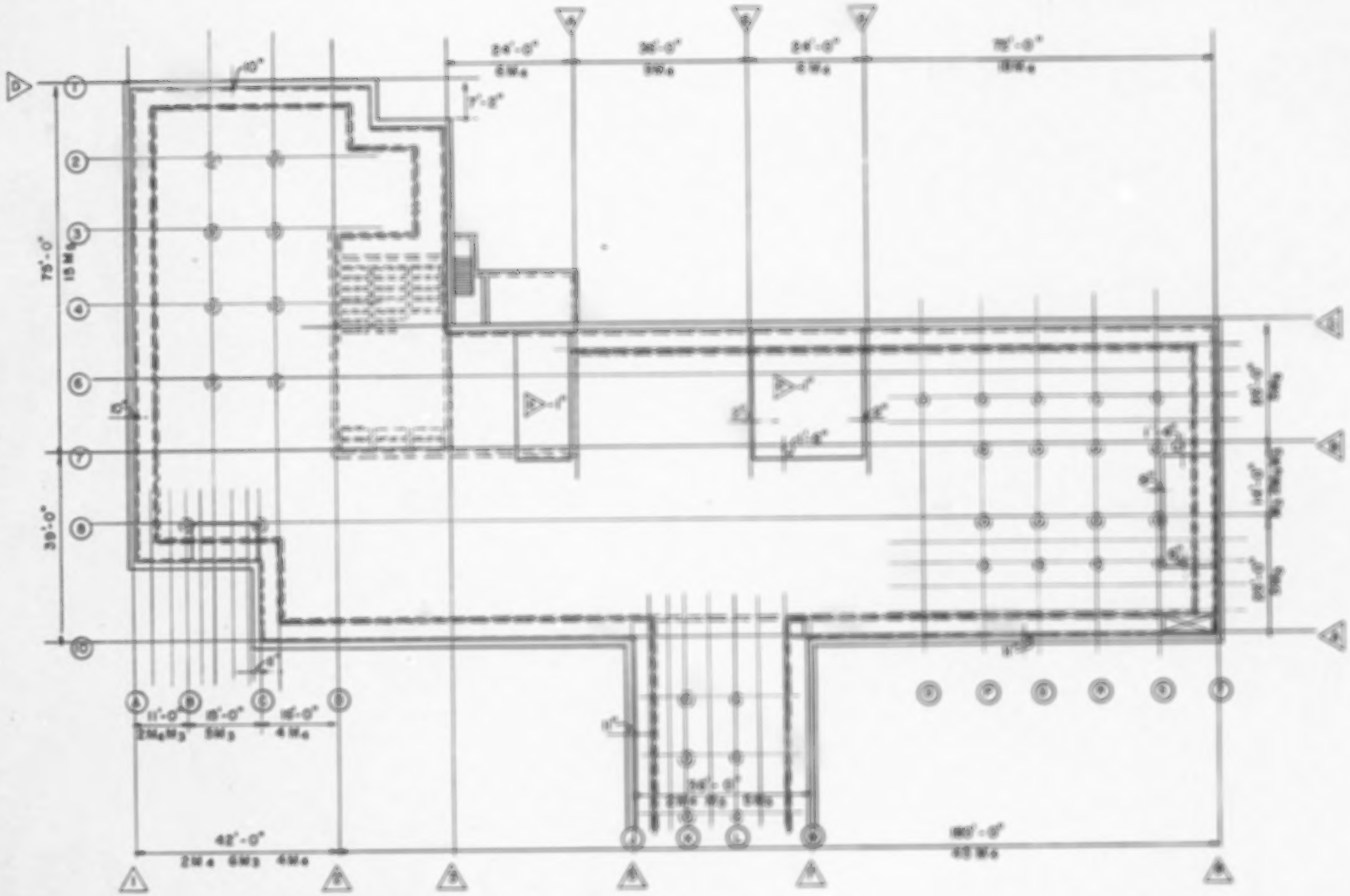


FIGURE 41 STRUCTURAL ELEMENTS: FIRST FLOOR PLAN

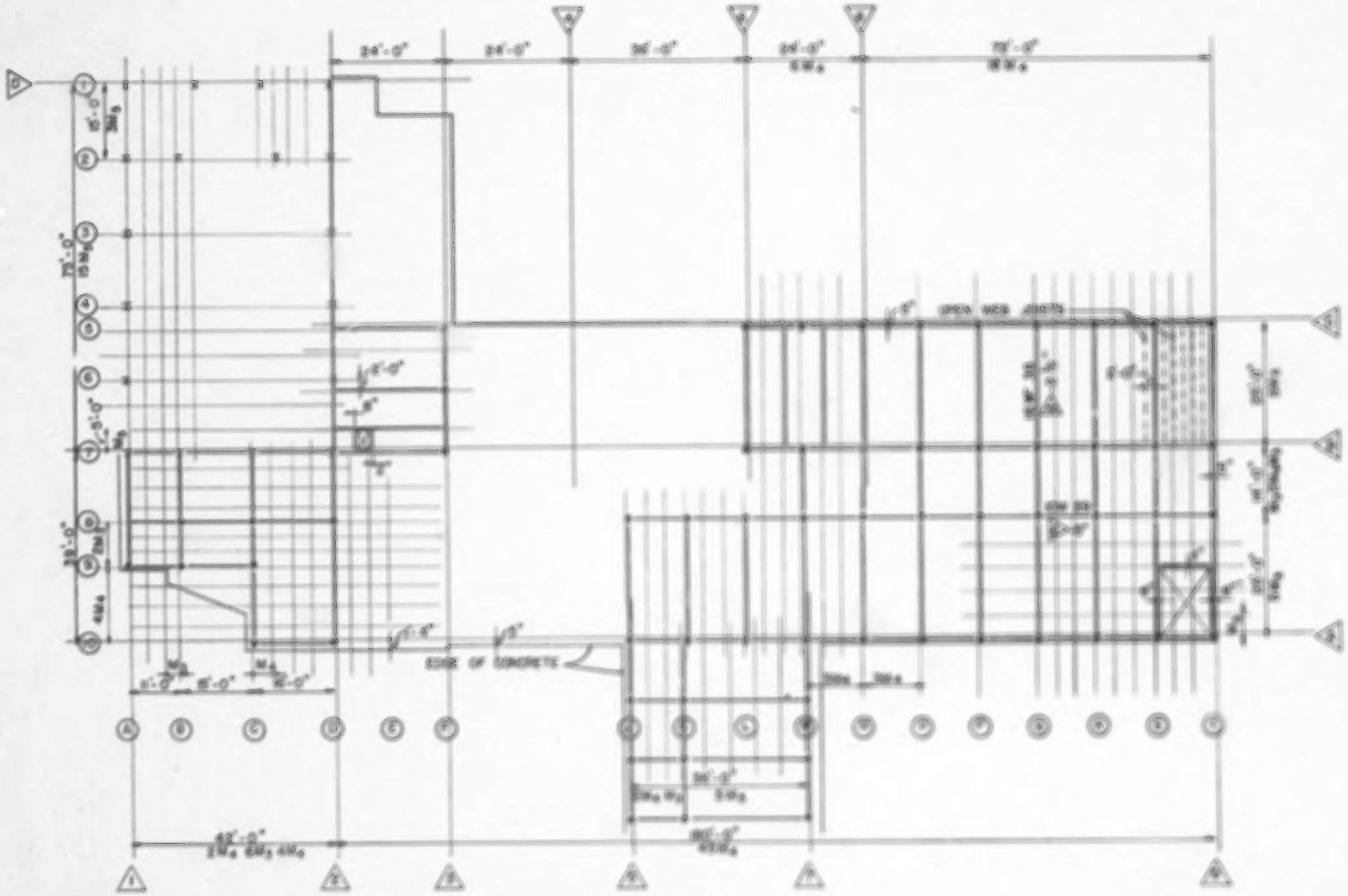


FIGURE 42 STRUCTURAL ELEMENTS: MODULATION SECOND FLOOR PLAN

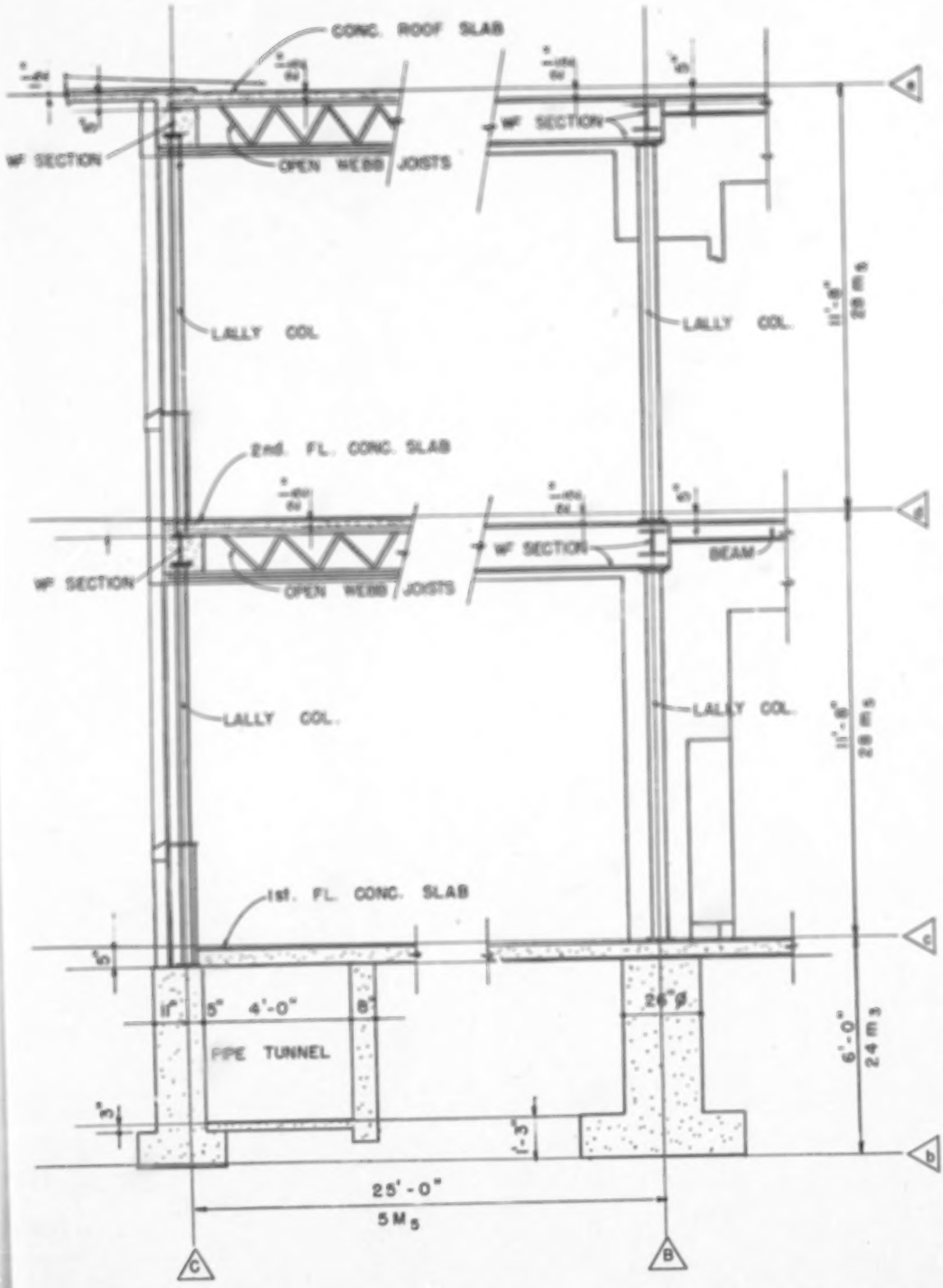
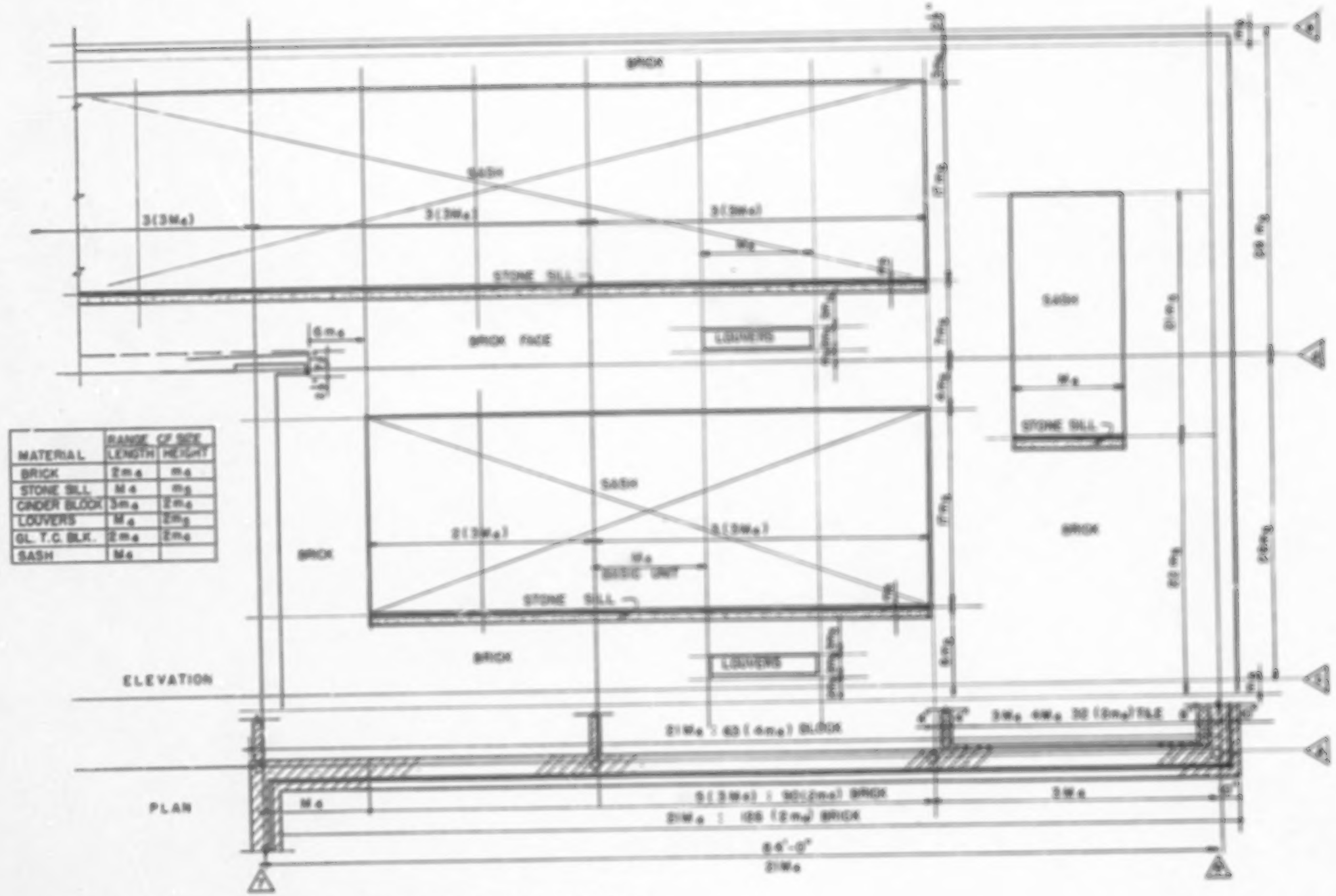


FIGURE 43 STRUCTURAL ELEMENTS : MODULATION SECTION



MATERIAL	RANGE OF SIZE LENGTH	RANGE OF SIZE HEIGHT
BRICK	2mo	mo
STONE SILL	Mo	mo
CINDER BLOCK	3mo	2mo
LOUVERS	Mo	2mo
GL. T.C. BLK.	2mo	2mo
SASH	Mo	

FIGURE 44 MODULATION: EXTERIOR WALL ELEMENT

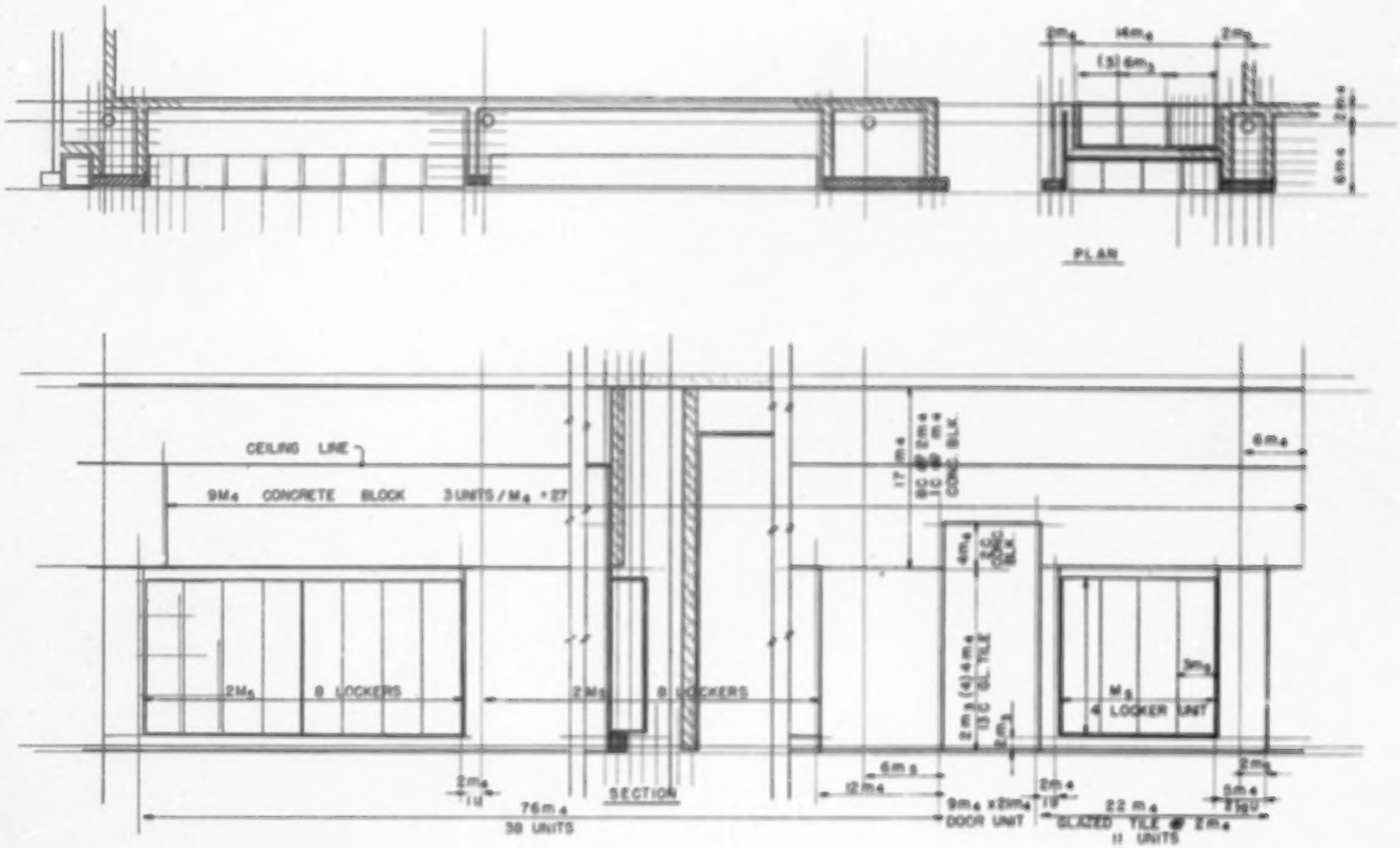


FIGURE 45 MODULATION: INTERIOR WALL ELEMENT

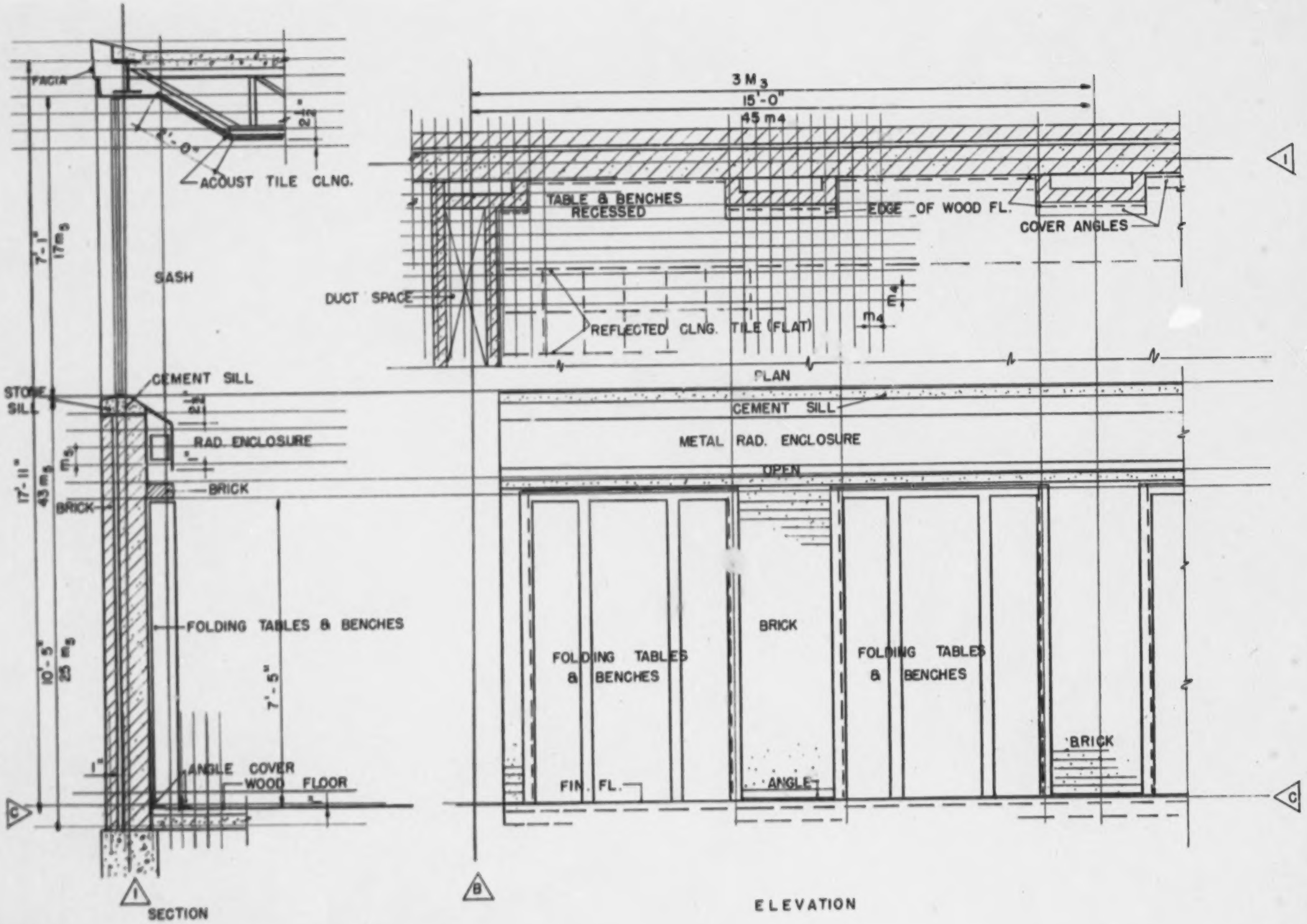
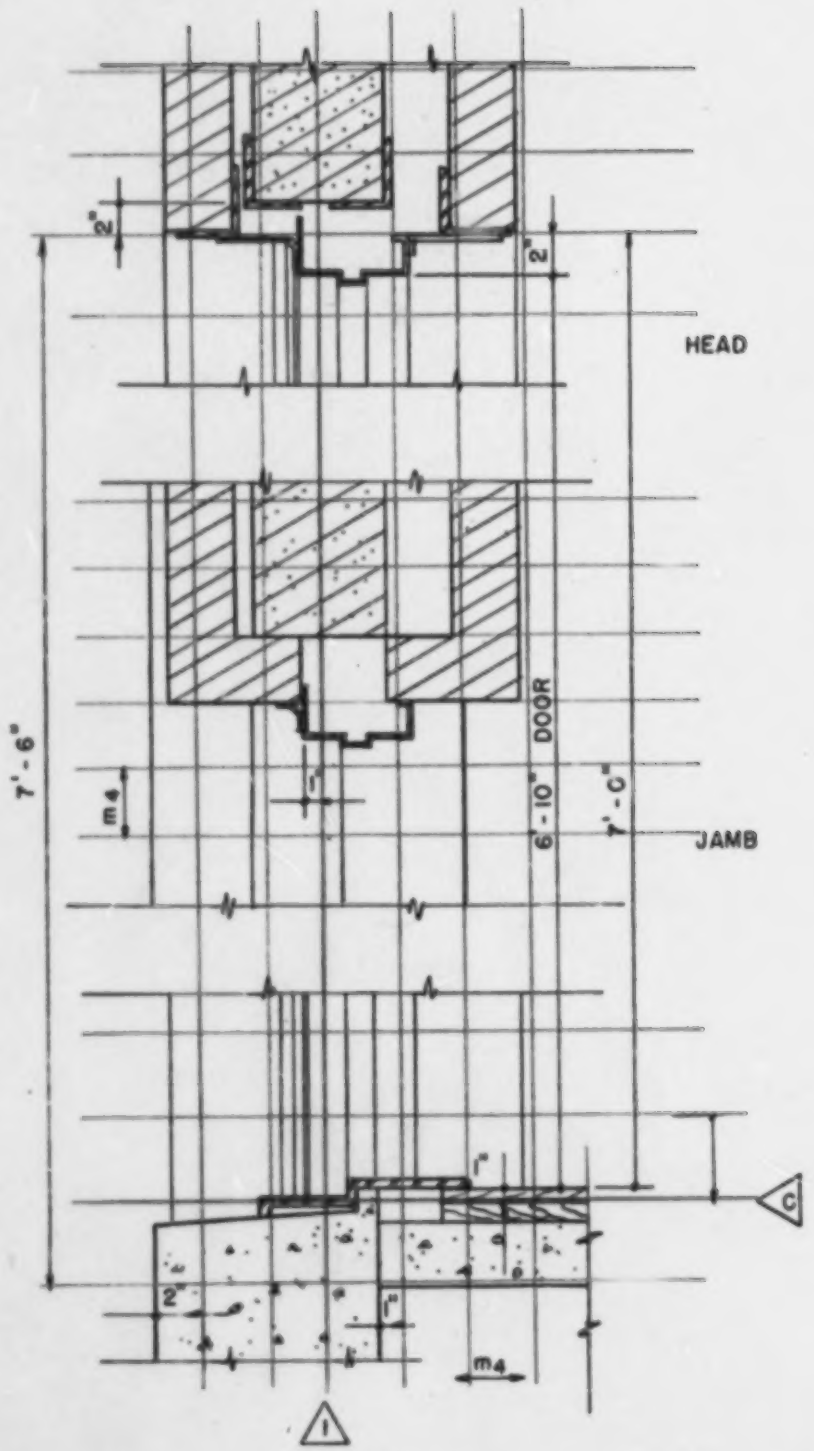


FIGURE 46 MODULATION: ALL PURPOSE ROOM DETAILS



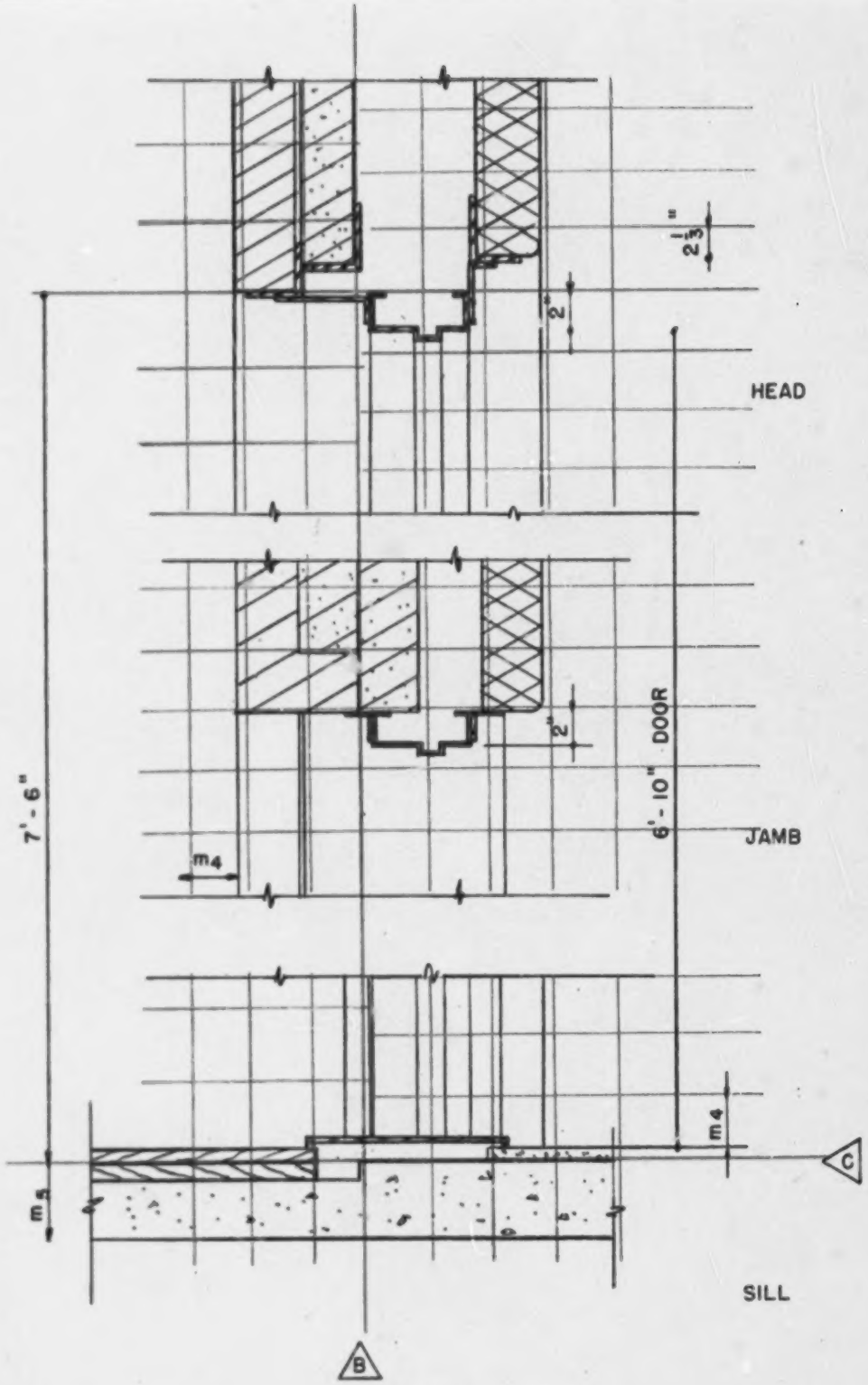


FIGURE 47 MATERIAL COMPONENTS: DOOR DETAILS ALL PURPOSE ROOM

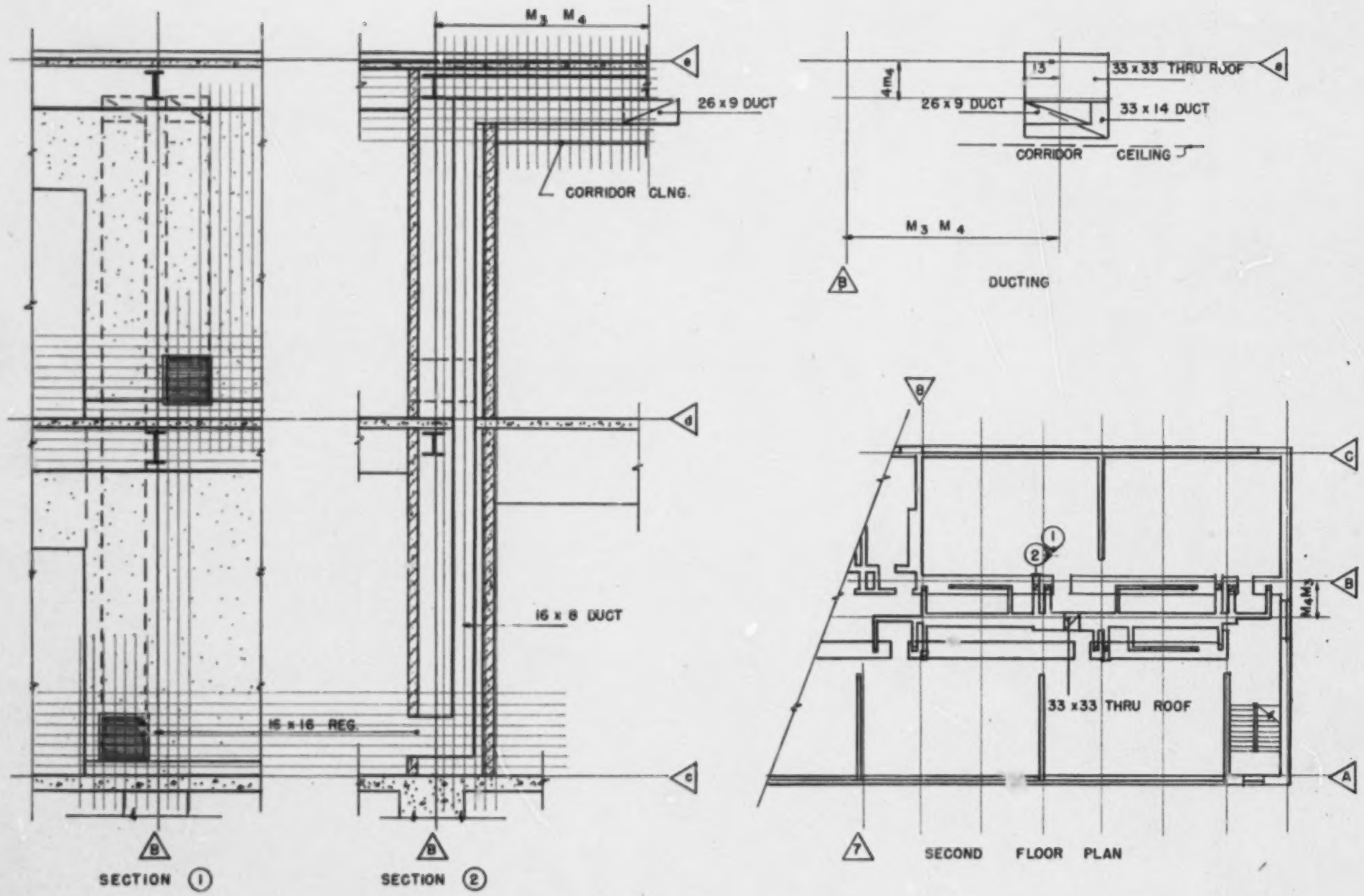
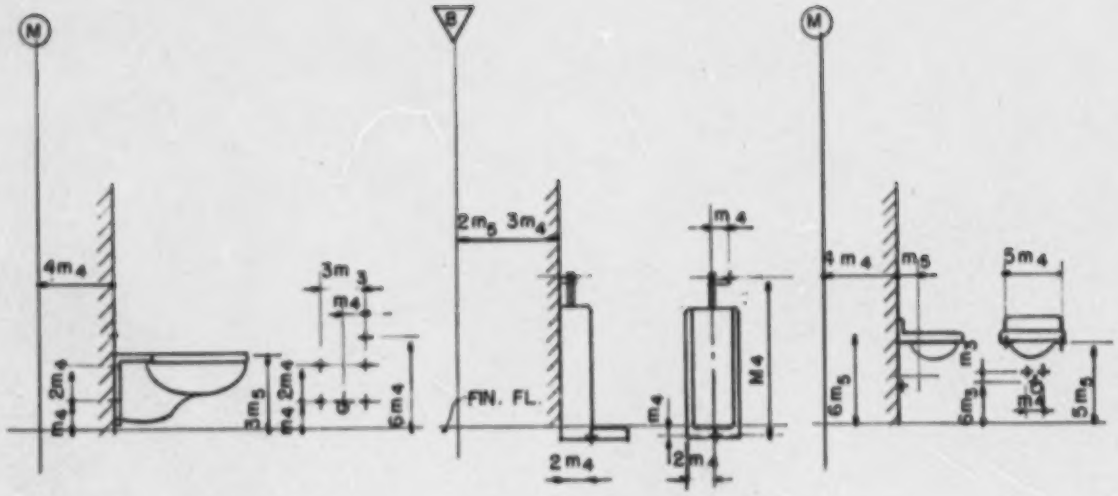
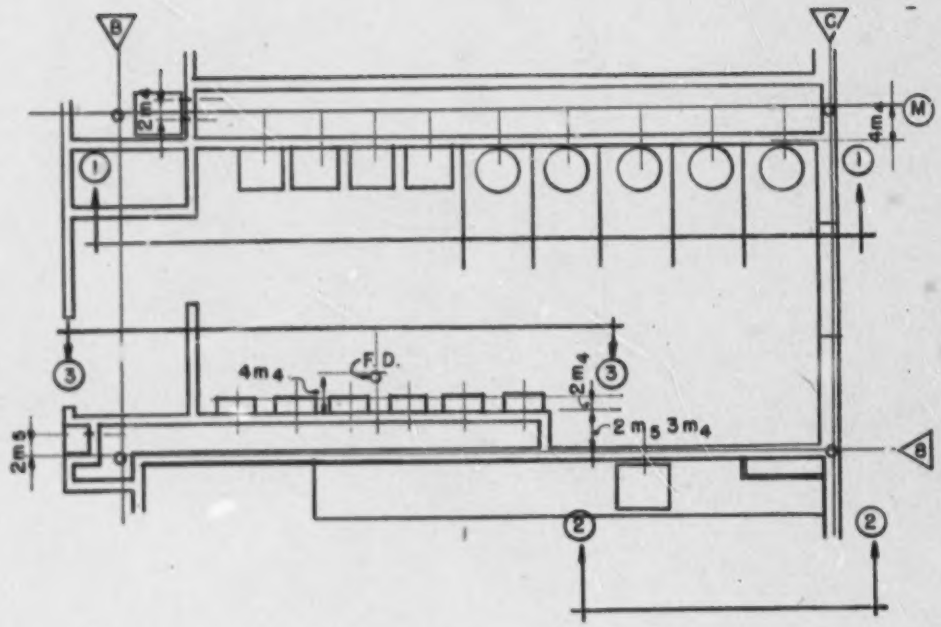


FIGURE 48 MECHANICAL EQUIPMENT : HEATING AND VENTILATING

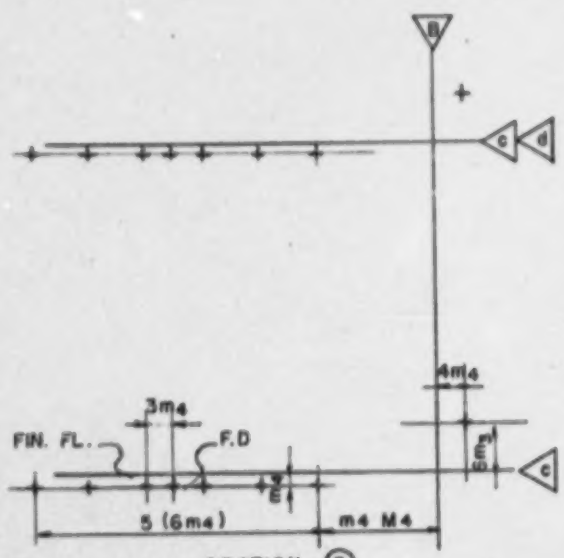


FIXTURES

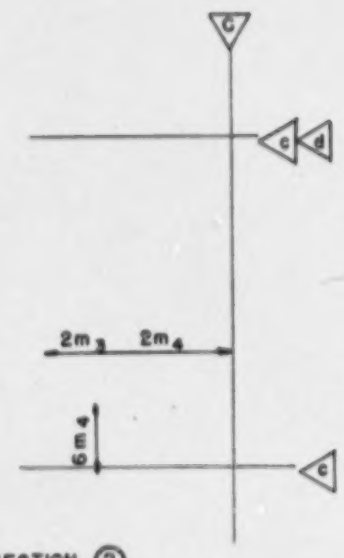
NOTE: SERVICE SINK, DRINKING FOUNTAIN AND COUNTER SINK ARE HANDLED SIMULAR TO THE FIXTURES ILLUSTRATED



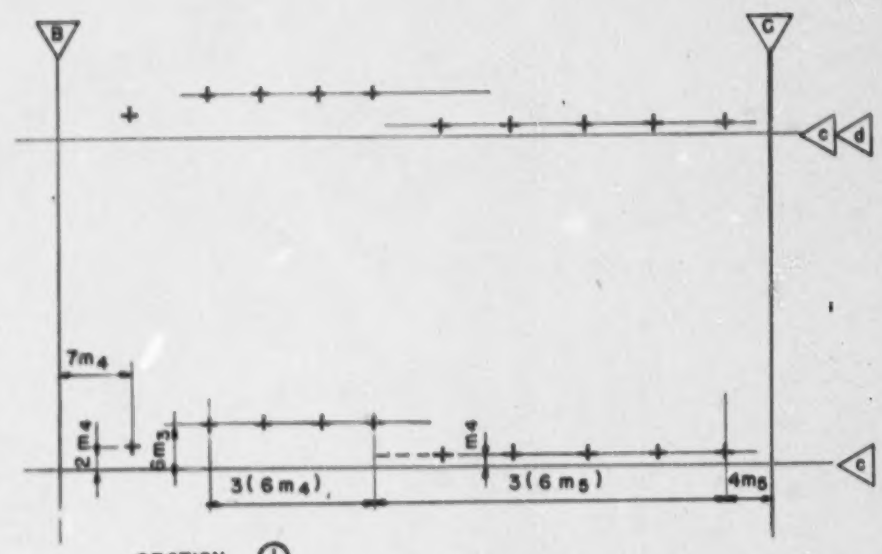
PLAN



SECTION ③



SECTION ②



SECTION ①

FIGURE 49 MECHANICAL EQUIPMENT: PLUMBING

6. FINDINGS AND CONCLUSIONS

This Cooperative Research Program has been concerned with modular coordination and the practices and procedures for design and construction of school building programs. As a result of the concentrated study effort, certain pertinent findings, conclusions and recommendations have been identified, all of which are related to the further advancement of the modular concept in the building industry.

Pertinent Findings

1. Previous study efforts within the subject of modulation dealt with or emphasized selected segments or portions of the total subject. These efforts have not resulted in complete systems involving all aspects, application procedures and techniques required for programing, design, manufacture and construction.

2. School building design and construction procedures require that any dimensional reference system should provide both flexibility and dimensional control. Flexibility should permit freedom in design and in the selection of appropriate dimensions and materials in accordance with variable but specific design criteria for each individual building project. Dimensional control should foster economies in construction. Both flexibility and dimensional control are to be utilized to the desired degree determined by the owner, designer, contractor, and fabricator.

3. The school building industry will welcome such a dimensional reference system.

4. The advance selection of a single basic unit of measure is not a sound prerequisite of a dimensional reference system.

Conclusions

1. It is possible to have a dimensional reference system for school building design and construction which will allow flexibility of design and have dimensional control. Three basic numerical coefficients (3, 4, 5) are utilized as an integral part of the system to provide flexibility. This allows freedom to design and construct and to select dimensional relationships for space, materials, etc. Simultaneously, that degree of dimensional control required by or suitable to each school building program may be exercised by those responsible for the program.

2. This system allows complete flexibility and provides dimensional control needed for the program requirements.

3. The proof of the attributes of this system will come only when the system is applied and those connected with the school building industry see the results.

Recommendations

It is recommended that:

All segments of the school building industry be encouraged to study, examine, evaluate and apply the developed system for purposes of critical review.

Special emphasis should be placed on an industry-wide educational program designed to inform educators, administrators, architects, engineers, manufacturers, fabricators and construction contractors, and their responsible personnel about the system and how it is used.

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ASSISTING FIRMS, AGENCIES, INSTITUTIONS AND INDIVIDUALS

William Allen, Director
Department of Scientific and Industrial Research
Building Research Station
Garston, Waterford, Herts, England

American Association of School Administrators
Washington, D. C.

American Council of Education
Washington, D. C.

American Institute of Architects
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Fehr and Granger
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Robert Hart, Architect
c/o John Carl Warnecke
San Francisco, California

Housing and Home Finance Agency
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Manufacturing Chemists' Association
Washington, D. C.

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New York City

Modular Buildings Standards Assn.
Washington, D. C.

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Texas Engineering Experiment Station
College Station, Texas

John Lyon Reid, Architect
San Francisco, California

Kenneth Reid, Architect*
c/o Ernest J. Kump
Palo Alto, California

Jack Robins, Architect
c/o John Lyon Reid
San Francisco, California

San Antonio Library
San Antonio, Texas

J. Stanley Sharp, Architect
c/o Ketchum, Gina and Sharp
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Building Research Section
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Palo Alto, California

Southwest Research Institute
Library
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Texas A & M College Library
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Mark Hartland Thomas, Secy.
The Modular Society Ltd.
London, England

Phillip Will, Jr., Architect
c/o Perkins and Will
Chicago 6, Illinois

John Worsley, Architect
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Palo Alto, California

William W. Wurster, Architect
c/o Wurster, Bernardi, Emmons
San Francisco, California

*Deceased

The list of architectural firms which contributed plans and specifications for the School Sample Study appears on the next page.

Clark R. Ackley
Aeck Associates
Albert & Michel
Anderson, Beckwith & Haible
The Architects Collaborative
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Atkins, Barrow and Asso.
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Dietrick-Knight & Asso.
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Wilmot C. Douglas
Eggers and Higgins
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Samuel Glaser and Asso.
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Hallman & Weems
Myrl Hanes Associates
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Bernard J. Hein and Hammel and Green
Hellmuth, Obata & Kassabaum, Inc.
Donald R. Hollis
Warren Holmes Company
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James M. Hunter & Asso.
Wm. B. Ittner, Inc.
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Edward D. James and Asso., Inc.
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Wm. Arild Johnson and Asso.
Jones, Lovegren, Helms & Jones
Kaestner and Kaestner
Ketchum and Sharp
Louis C. Kingscott & Asso., Inc.
Donald Beach Kirby
Carl Koch & Asso.
Ernest J. Kump
Lawrence, Dykes and Asso.
Lillis & Smith
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